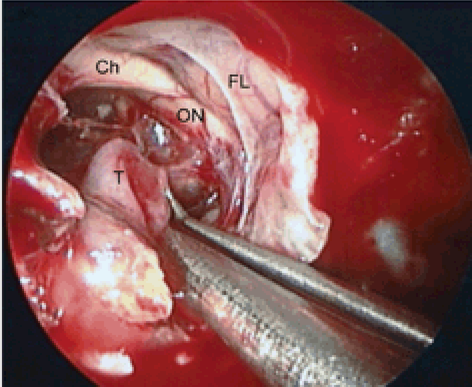
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# Introduction

## Endoscopy in neurosurgery

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During the last 2 decades endoscopy and its main instrument, the endoscope, have significantly changed some areas of neurosurgery and made possible new others. As a matter of fact, the possibility now exists for neurosurgeons to access deep, hidden, and sometimes formidable areas of the nervous system thanks to light transmission, panoramic views, and angled lines of sight brought by the endoscope. These features have dramatically burst open the repertoire of neuroendoscopic techniques that are now being commonly performed for pathologies within the cranial compartment, skull base, spinal cord, and peripheral nerves. In fact, the management of some neurosurgical disorders has been redefined with new standards. While the technological breakthrough has been profound, there remain substantial hurdles in advancing the field of endoscopic neurosurgery, most notably global neurosurgical training and equipment innovation. Even with these limitations, it is certain that the integration of endoscopic techniques in neurosurgery is permanent and indispensible. We hope you enjoy this issue of *Neurosurgical Focus*. *(DOI: 10.3171/2011.4.FOCUS.Intro)*

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# Long-term operative failure of endoscopic third ventriculostomy in pediatric patients: the role of cine phase-contrast MR imaging

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*Object.* Although a rarely reported occurrence, late failure of endoscopic third ventriculostomy (ETV) may occur in children as a result of a variety of factors. Delay in recognition of symptoms can lead to harmful deterioration in the patient's condition. The authors undertook this study to assess the capacity of cine phase-contrast MR imaging to identify late failure in asymptomatic pediatric patients treated with ETV for hydrocephalus.

*Methods.* This study was a retrospective evaluation of cases involving patients who underwent ETV between January 1, 1999, and December 31, 2008, at the pediatric neurological surgery service of the University of Padua. Before 2004, patients were routinely followed up with cine MR imaging at 3, 6, and 12 months after ETV. In 2004, a protocol of annual cine MR follow-up was instituted as a result of a case of fatal late failure. The authors evaluated all cases of late failure identified through cine MR imaging and performed a statistical analysis to investigate the relationship between ETV failure and several variables, including the cause of hydrocephalus for which ETV was originally indicated.

*Results.* In a series of 84 patients (age range 6 days–16 years), 17 patients had early ETV failure. Of the remaining 67 patients, 5 (7%) were found to have no CSF flow through the fenestration and recurrent ventriculomegaly when assessed with cine MR imaging at 1, 2, 3, 4, and 7 years after ETV. The patient in whom ETV failure was identified 1 year postoperatively had Dandy-Walker malformation. The patients in whom ETV failure was identified 2, 3, and 4 years postoperatively all had undergone ETV for treatment of postinfective hydrocephalus. The patient in whom ETV failure was identified 7 years postoperatively had a cystic arachnopathy in the fourth ventricle after cerebellar astrocytoma removal.

*Conclusions.* Patients who undergo ETV for infective hydrocephalus and Dandy-Walker malformation should receive long-term follow-up, because late closure of the stoma may occur progressively and slowly. Intraoperative observation of thickened arachnoid membranes at the level of the interpeduncular cisterns at the first ETV and a progressive decreasing of CSF flow through the stoma on routine cine MR imaging should be considered unfavorable elements entailing a significant risk of deterioration. *(DOI: 10.3171/2011.1.FOCUS10303)*

**Key Words** • **endoscopic third ventriculostomy** • **pediatric hydrocephalus** • **cine phase-contrast MR imaging**

The long-term success of ETV in the treatment of primary aqueductal stenosis in pediatric patients has been widely discussed in the literature.[2] On the other hand, the long-term outcome of obstructive hydrocephalus in patients with a history of IVH or infection or in those with hydrocephalus associated with tumors of the posterior fossa or of the quadrigeminal and pineal regions, myelomeningocele and Chiari malformation Type II, or Dandy-Walker syndrome, has been the object of few articles concerning patients under 16 years of age.[23,24] Late closure of the stoma in patients with these kinds of hydrocephalus can be manifested by signs of sudden-onset intracranial hypertension and can have potentially disastrous consequences.[3,11,18] The aim of this article is to assess the capacity of cine phase-contrast MR imaging to identify early and long-term obstruction of the stoma and to discuss etiological and anatomical factors as well as endoscopic findings that might be useful for predicting later failure.[15] We consider early failure of ETV to be failure within the 1st year after the procedure, whereas long-term failure is defined as failure occurring at least 1 year after the endoscopic treatment.[5] In this paper we report the results of our analysis of clinical and cine MR imaging findings in pediatric patients who underwent ETV between January 1999 and December 2008.

*Abbreviations used in this paper:* ETV = endoscopic third ventriculostomy; IVH = intraventricular hemorrhage.

## Methods

This study was prompted by a fatal outcome of a case in 2004. The child died 1320 days after undergoing ETV for hydrocephalus linked to Dandy-Walker syndrome; she had signs of fatal intracranial hypertension and an occluded stoma demonstrated by cine MR imaging. This patient had not been followed up with radiological evaluation beyond 1 year after ETV because she did not show any signs or appear to experience any symptoms of intracranial hypertension.

The study consisted of a retrospective analysis of 84 cases involving patients ranging in age from 6 days to 16 years at the time of ETV. These patients had originally been selected for a first ETV after MR imaging confirmed enlargement of the lateral and third ventricles with absence or reduction of systolic/diastolic flow void through the sylvian aqueduct and the fourth ventricle outlet. The ETVs were performed at a single institution (University of Padua) by the same neurosurgeon (R.F.) between January 1, 1999, and December 31, 2008. A correct technical execution of ETV requires an adequate diameter of the stoma in the floor of the third ventricle and the perforation of the arachnoid membranes in the interpeduncular cistern, using a flexible endoscope, a monopolar wire, and balloon catheter.[10]

In 52 of these 84 patients, ETV was performed as a primary procedure and in 32 it was performed after shunt malfunction.

The follow-up assessments included an analysis of neurological evaluations and cine MR imaging at 3, 6, and 12 months after the procedure to identify early failure of ETV. Before the death of the child described above, cine MR imaging was not routinely performed beyond 12 months postoperatively. In 2004, however, the protocol was changed, and follow-up was continued on an annual basis. In cases in which more than a year had elapsed since radiological examination, the patients were re-examined with cine MR imaging and followed up annually thereafter with additional cine MR imaging.

The MR imaging examinations were performed using a 1.5 T scanner (Achieva; Philips Medical Systems) with a phased-array head coil and with patients placed supine. Cine phase-contrast axial and sagittal MR images were obtained using retrospective cardiac gating to evaluate CSF flow. The qualitative flow parameters were acquired in a plane perpendicular to the long axis of the aqueduct, passing through its midportion (TR 23 msec, TE 14 msec, flip angle 15°, field of view 80 × 80, pixel size 0.38 × 0.55 mm, matrix 208 × 145). The flow-velocity sensitivity (velocity encoding) was set at 15 cm/second. The scanning time varied from 7 to 9 minutes depending on the heart rate. On midsagittal MR images, cranial flow was seen as a bright signal and caudal flow as a dark signal.[1,17]

### *Statistical Analysis*

Plots showing ETV failure as identified by cine MR imaging were calculated using the Kaplan-Meier method, and differences in the occurrence of ETV failure in patients who had postinfective hydrocephalus and those with hydrocephalus due to other causes were evaluated with the log-rank test. Student t-tests were used for normally distributed variables, while for non-normally distributed variables, the Mann-Whitney U-test or the Kruskal-Wallis test were performed. For nominal variables, the chi-square or Fisher exact test was used. Significance was set at $p < 0.05$.

The day of the surgery for shunt placement was considered the end point in cases of failure. The etiology of hydrocephalus, patient age at initial ETV, and shunt malfunction as a reason for ETV were analyzed.

## Results

### *Population*

Cases involving 84 children (51 boys and 33 girls) were reviewed for this study. The children's mean age (± SD) at the time of ETV was 5.4 ± 4.9 years (median 4.6, range 6 days–16 years). There was no significant difference in mean ages between the male and the female patients. The cause of hydrocephalus was related to infection (postinfective hydrocephalus) in 9 cases, aqueductal stenosis in 22, spina bifida in 14, expansive tumor with posterior fossa involvement in 16, hemorrhage in 18, and Dandy-Walker malformation in 5 (Table 1). In 32 cases, the ETV was performed after a shunt malfunction. The mean duration of the shunt treatment was 8.2 ± 3.9 years (median 8.4 years, range 1–15.9 years).

### *Hemorrhagic/Infective Hydrocephalus*

Of 27 patients with posthemorrhagic or postinfective hydrocephalus, 9 (6 post-IVH and 3 postmeningitic) presented with an early failure between 2 and 76 days after ETV (median 27 days). Cine phase-contrast MR imaging in the remaining 18 asymptomatic patients (13 with post-IVH hydrocephalus and 5 with postinfective hydrocephalus) documented an obstruction of the stoma with an increase in ventricular size, without any neurological signs or symptoms in 3 cases of postmeningitic hydrocephalus: in 2 patients, 2 and 6 years after ETV was performed for shunt malfunction, and in 1 case, 4 years after ETV was performed for newly diagnosed hydrocephalus (when the patient was 4 years old).

**TABLE 1: Incidence of early failure of ETV stratified by cause of hydrocephalus***

| Cause of Hydrocephalus | Total No. of Cases | Early ETV Failure No | Early ETV Failure Yes |
|---|---|---|---|
| infection | 9 (10.7) | 6 (66.7) | 3 (33.3) |
| aqueductal stenosis | 22 (26.2) | 18 (81.8) | 4 (18.2) |
| spina bifida | 14 (16.7) | 11 (78.6) | 3 (21.4) |
| tumor | 16 (19) | 15 (93.7) | 1 (6.3) |
| hemorrhage | 18 (21.4) | 12 (66.7) | 6 (33.3) |
| DWM | 5 (6) | 5 (100) | 0 |
| all causes | 84 (100) | 67 (79.7) | 17 (20.3) |

* Values represent numbers of cases (%). Abbreviation: DWM = Dandy-Walker malformation.

*Hydrocephalus Due to Aqueductal Stenosis*

Of 22 patients who underwent ETV for secondary hydrocephalus due to aqueductal stenosis, 4 (18%) experienced ETV failure between 7 and 16 days postoperatively. In the remaining 18 patients, stoma patency was monitored with cine phase-contrast MR imaging for a median of 75 months (range 14–128 months) after treatment.

*Tumor-Related Hydrocephalus*

Ten patients were treated for hydrocephalus related to a posterior fossa tumor (cerebellar pilocytic astrocytoma in 6 cases, medulloblastoma in 3, ependymoma in 1). In all but one of these patients, cine MR imaging performed between 50 and 122 months (median 90 months) after ETV showed restoration of CSF flow from the third ventricle through the sylvian aqueduct to the fourth ventricle. All these patients studied with cine MR imaging showed reduced ventricle size, presence of flow through the aqueduct, and closure of the stoma (which was no longer necessary after tumor resection). Patients with tumoral hydrocephalus had a greater reduction in ventricle size than patients with other kinds of hydrocephalus.

The only patient with tumor-related hydrocephalus in whom we identified late failure had originally undergone ETV at 2 years of age, before resection of a cerebellar astrocytoma. Cine MR imaging performed 7 years later showed obstruction of the stoma with enlargement of the ventricles; shunt placement was necessary to treat the ventriculomegaly.

Of 6 patients treated with ETV for hydrocephalus related to neoplasms of the quadrigeminal and pineal region, 1 was treated with a shunt for an obstruction of the stoma 3 months after the resection of a pineal teratoma. A patient with a tectal plate glioma underwent a repeat ETV, 11 months after the first one, for closure of the stoma by gliotic tissue of the third ventricular floor.

*Myelomeningocele-Related Hydrocephalus*

Fourteen patients underwent ETV for treatment of hydrocephalus associated with Chiari malformation Type II. In 7 of these patients, ETV was performed as an initial procedure for the treatment of hydrocephalus; in 3 of these patients, who were all under 1 month of age at the time of ETV, the procedure failed, whereas in the other 4, who were all over 2 months of age at surgery, the procedure was successful. In the remaining 7 patients, ETV was performed because of shunt malfunction, and none of these patients experienced ETV failure. (Published studies of ETV in patients with myelomeningocele have shown that the outcome is better in patients who have previously been treated with shunt placement than in those who undergo ETV in their first months of life as the initial treatment for hydrocephalus.[19,21,25])

*Hydrocephalus Associated with Dandy-Walker Malformation*

The 5 patients with Dandy-Walker malformation had significant enlargement of the ventricles and aqueductal patency on preoperative cine MR imaging—even the 2 patients undergoing ETV due to a shunt malfunction. The endoscopic procedure was used not only to perform the third ventriculostomy, but also for a transaqueductal inspection, and to confirm the membranous obstruction of the foramina of Luschka and Magendie, which are very difficult to evaluate with MR imaging. Cine MR imaging 14–97 months after ETV demonstrated an occluded stoma and increased ventricle size in 1 of these 5 patients (14 months after ETV) and a reduction of cyst and ventricle size in only 1 patient.

*Comparison of Early and Late Failure Cohorts*

A statistical analysis was performed to compare the early ETV failure and late ETV failure cohorts with respect to hydrocephalus etiology, patient age at ETV, and shunt malfunction as the reason for ETV.

Early ETV failure occurred in 17 cases at a mean ± SD of 57 ± 44 days postoperatively (median 57 days, range 2–179 days; Fig. 1). There was no significant difference in the percentage of failures with respect to hydrocephalus etiology (chi-square test, $p = 0.30$; Table 1). Nevertheless, it can be noted that the highest rates of early ETV failure occurred in patients with postinfective hydrocephalus (33.3%), posthemorrhagic hydrocephalus (33.3%), and spina bifida (21.4%). Among the patients with posterior fossa tumors, only 1 experienced early ETV failure (a rate of approximately 6%). There was no case of early ETV failure among the patients with Dandy-Walker malformation (although this was a smaller group with only 5 patients).

There was no significant difference in the length of period between the ETV and early failure with respect to causes of hydrocephalus (Kruskal-Wallis ANOVA, $p = 1$). There was no significant difference in rate of early ETV failure with respect to shunt malfunction as the reason for ETV (18% early ETV failure rate in patients with shunt failure vs 21% in those who did not have previous shunt placement; chi-square test, $p = 0.8$). The mean age at ETV placement was lower in the group with early ETV failure (3.6 ± 4.8 years, in contrast with 5.9 ± 4.9 years in those who did not experience early failure; $p = 0.08$).

In the remaining 67 cases (excluding the 17 early failures), the children were asymptomatic. Cine MR imaging, however, showed an obstruction of the stoma in 5 of these patients. Notably, ETV failure occurred in 50% (3 of 6)

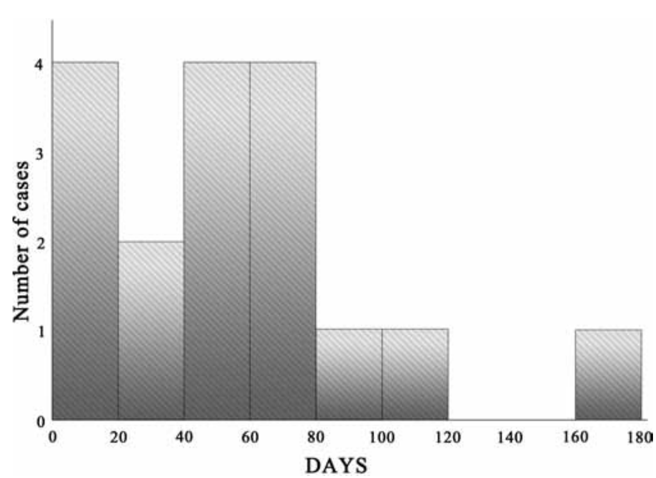


**Fig. 1.** Bar graph showing the time between ETV and early failure.

of the cases of postinfective hydrocephalus (Table 2). The incidence of late failure was significantly higher in children with postinfective hydrocephalus than in those with hydrocephalus of other causes (bilateral Fisher exact test, p = 0.004). Three of the 5 children with late failure identified by cine MR imaging had undergone ETV for shunt failure, but there was no statistically significant association between previous shunt placement and late ETV failure (p = 0.31). Similarly in this group of 32 children who had shunt malfunction, there was no significant association between pathology and obstruction of CSF flow (p = 0.34). Cine MR imaging showed a failure of the ETV in these 5 children after a mean period of 4 ± 2.5 years (median 4 years, range 1.2–7.1 years). In the 3 cases of postinfective hydrocephalus, the period between the ETV procedure and failure was 2, 4, and 6 years; in the patient with the posterior fossa tumor the period was 7 years, and for the patient with Dandy-Walker malformation it was a little more than 1 year.

The mean age at ETV was lower in the patients who experienced early failure than in those who experienced late failure (3.3 ± 1.9 years vs 6.1 ± 5 years). However, this difference was not significant (Mann-Whitney U-test, p = 0.38).

In the 67 patients who did not experience early ETV failure, the overall mean duration of follow-up was 6 ± 2.8 years (median 6.5, range 0.8–10.5 years). Figure 2 presents the Kaplan-Meier plots showing the failure of the ETV, comparing the group with postinfective hydrocephalus with those with hydrocephalus due to other causes; log-rank testing showed a statistically significant difference (p = 0.00004). The median of the plot related to the infective pathology is at 5.8 years (95% CI 3.2–8.5 years).

In 12 patients (18% of the group of 67), who had no signs or symptoms of intracranial hypertension, MR imaging showed ventricular size reduction and no flow through the ventriculostomy. Nine of these patients, who had been treated for posterior fossa tumors, had prolonged follow-up ranging from 16 to 118 months.

Revision ETV was performed for occlusion of the stoma on the basis of MR imaging in only 4 patients (2 with myelomeningocele, 1 with aqueductal stenosis, and 1 with tectal plate gliomas). The procedure was successful in all 4 cases, and no other patients required any additional procedures for issues related to CSF flow.

**TABLE 2: Incidence of "no flow" findings on cine MR imaging (late failure) stratified by cause of hydrocephalus***

| Cause of Hydrocephalus | Total No. of Cases | Late ETV Failure | |
|---|---|---|---|
| | | No | Yes |
| infection | 6 (9) | 3 (50) | 3 (50) |
| aqueductal stenosis | 18 (26.9) | 18 (100) | 0 |
| spina bifida | 11 (16.4) | 11 (100) | 0 |
| tumor | 15 (22.4) | 14 (93.3) | 1 (6.7) |
| hemorrhage | 12 (17.9) | 12 (100) | 0 |
| DWM | 5 (7.4) | 4 (80) | 1 (20) |
| all causes | 67 (100) | 62 (92.5) | 5 (7.5) |

* Values represent number of cases (%).

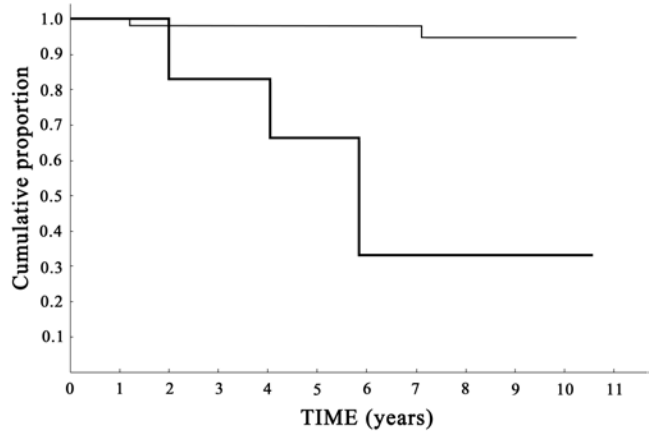


**Fig. 2.** Kaplan-Meier plots showing time to ETV failure in patients with hydrocephalus related to infection *(thick line)* compared with other causes *(thin line).*

## Discussion

Cases with prolonged follow-up and late failure of ETV were described by Cinalli et al.[2] (range of follow-up 1 month–6 years), Siomin et al.[23] (8 days–6 years), Wagner and Koch[26] (2 weeks–6 years), and Mohanty et al.[20] (8 weeks–2 years). In an article published in 2007, Lipina et al.[18] reported the case of an 11-year-old girl who died of late ETV failure. In reviewing the literature, they identified 13 other reported cases, bringing the total of reported cases, including their own, to 14 (8 with obstructive hydrocephalus associated with aqueductal stenosis, 4 with congenital hydrocephalus, and 2 with tumors of the quadrigeminal region). Analyzing these cases, they found that the time from ETV to death ranged from 1 month to 7 years, and that 8 of the 14 patients had undergone ETV after a shunt malfunction. In these series cine MR imaging was only performed later than 1 year after ETV when there were symptoms of failure. Fukuhara and colleagues[7,8] used cine MR images to confirm an obstruction of the stoma, but only considered a cine MR imaging finding of obstruction diagnostic when the patients presented with signs of intracranial hypertension.

Reviewing the literature about delayed failures in pediatric patients with secondary obstructive hydrocephalus or hydrocephalus associated with Dandy-Walker syndrome,[18] we were unable to find reports of routine radiological follow-up after the first few years following endoscopic treatment.

The prolonged postoperative cine MR imaging follow-up (6 ± 2.8 years) in 67 patients with different hydrocephalic pathologies, without signs or symptoms at the time of imaging, is what makes our study unique. Obviously, in some of these patients the repeated imaging was "unnecessary," but our aim was to identify particular etiological types of hydrocephalus that require long-term follow-up with cine MR imaging.

In our pediatric series, in contrast to the article of Lipina et al.,[18] there were no late ETV failures in patients with obstructive hydrocephalus associated with aqueductal stenosis. In these cases the obstruction of the stoma, as has been described, happens rapidly and is related to a defect in the CSF absorptive capacity. In our series, ETV was repeated 1 year after the first surgery for closure of the stoma by gliotic tissue in only 1 patient with tectal plate glioma.

Our cine MR imaging studies carried out between 2007 and 2008 demonstrated that, of 67 patients, 5 children had an obstruction of the stoma and an increase of the dimensions of the ventricle cavities, without neurological signs and symptoms 1, 2, 4, and 7 years after ETV, after at least 3 cine MR imaging studies showing patency of the stoma and unchanged ventriculomegaly. Three of these 5 patients had postinfective hydrocephalus,[13] one had Dandy-Walker syndrome, and the last had a posterior fossa tumor. In the patients with postinfective hydrocephalus, thickened arachnoid membranes were observed at the level of the interpeduncular cisterns during the initial ETV, but there was a good flow through the stoma at the end of the procedure. In 2 cases of Dandy-Walker syndrome (including the one with a fatal outcome that prompted this study), the patients had a late closure of the stoma, without neurological signs of increased intracranial pressure. In the patient who had undergone resection of a cerebellar pilocytic astrocytoma (without tumor seeding or extension at the level of the prepontine cistern), cine phase-contrast MR imaging 3 years after ETV demonstrated flow through the stoma and cystic arachnopathy in the fourth ventricle. Reduction of the ventricle size had not been achieved after the radical removal of the tumor, and this can be considered as an anatomical predictive element of treatment failure in patients treated for a neoplasm of the posterior fossa.[6,22] Nevertheless, nothing was observed during the original ETV procedure in any of the 5 cases that would suggest that these patients were at particular risk for long-term ETV failure. Furthermore, the possibility of disastrous consequences increases because neurological symptoms may also manifest some months after complete occlusion of the stoma, with exhaustion of physiological mechanisms of compensation.

The obstruction of the stoma demonstrated by the cine MR images was controlled with a new endoscopic procedure in all 5 children. In each case intraoperative diagnostic observation demonstrated that the closure of the stoma was caused by the gliotic tissue and by the new formation of arachnoid membranes in the interpeduncular cistern. The analysis of these intraoperative observations suggested a high risk of failure of ETV, justifying shunt placement during the same operation. This approach, as described by Warf and Kulkarni,[27] should also be applied at the time of the first ETV to avoid the risk of late failure. In this series, in contrast to that of Hader et al.,[12] there was no statistically significant difference in the rate of ETV failure when comparing patients who had or had not undergone previous shunt placement. It has been confirmed that infants with postinfective hydrocephalus, posthemorrhagic hydrocephalus, and hydrocephalus associated with spina bifida[19,21,25] have a high risk of ETV failure when the procedure is performed before they reach 2 months of age. Kadrian et al.[14] observed that ETV success is strongly dependent on patient age, with 41% of patients who underwent ETV at 1–6 months of age still presumed to have a functioning ETV 5 years postoperatively.[14] These reported data and the fact that the formation of gliotic membrane in the stoma and the interpeduncular cistern is more common in infants than adults, suggest the need for close follow-up with cine MR imaging to reveal an early malfunction.[4,9,16,26]

## Conclusions

Cine phase-contrast MR imaging has a high capacity to detect a flow defect through a ventriculostomy, raising the suspicion of ETV failure. It remains to be established how long-term follow-up should be continued. In this retrospective study, 20 of 67 patients in whom follow-up cine MR imaging was performed were studied at least 7 years after ETV, and in these 20 patients, cine MR imaging showed no obstruction of the stoma. The number of patients in this study is still too small to allow definitive conclusions to be drawn, but we have attempted to define a population of patients (those with postinfective hydrocephalus or hydrocephalus associated with Dandy-Walker malformation) who may be at an increased risk for late ETV failure.

#### Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper. No funds were received in support of this work. No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.

Author contributions to the study and manuscript preparation include the following. Conception and design: Faggin. Acquisition of data: Faggin, Denaro, Meneghini, Calderone. Critically revising the article: Faggin. Reviewed final version of the manuscript and approved it for submission: all authors. Statistical analysis: Faggin. Administrative/technical/material support: Calderone.

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# Neuroendoscopic biopsy of ventricular tumors: a multicentric experience

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*Object.* Although neuroendoscopic biopsy is routinely performed, the safety and validity of this procedure has been studied only in small numbers of patients in single-center reports. The Section of Neuroendoscopy of the Italian Neurosurgical Society invited some of its members to review their own experience, gathering a sufficient number of cases for a wide analysis.

*Methods.* Retrospective data were collected by 7 centers routinely performing neuroendoscopic biopsies over a period of 10 years. Sixty patients with newly diagnosed intraventricular and paraventricular tumors were included. No patient harboring a colloid cyst was included. Data regarding clinical presentation, neuroimaging findings, operative techniques, pathological diagnosis, postoperative complications, and subsequent therapy were analyzed.

*Results.* In all patients, a neuroendoscopic tumor biopsy was performed. In 38 patients (64%), obstructive hydrocephalus was present. In addition to the tumor biopsy, 32 patients (53%) underwent endoscopic third ventriculostomy (ETV), and 7 (12%) underwent septum pellucidotomy. Only 2 patients required a ventriculoperitoneal shunt shortly after the endoscopy procedure because ETV was not feasible. The major complication due to the endoscopy procedure was ventricular hemorrhage noted on the postoperative images in 8 cases (13%). Only 2 patients were symptomatic and required medical therapy. Infection occurred in only 1 case, and the other complications were all reversible. In no case did clinically significant sequelae affect the patient's outcome. Tumor types ranged across the spectrum and included glioma (low- and high-grade [27%]), pure germinoma (15%), pineal parenchymal tumor (12%), primary neuroectodermal tumor (4%), lymphoma (9%), metastasis (4%), craniopharyngioma (6%), and other tumor types (13%). In 10% of patients, the pathological findings were inconclusive. According to diagnosis, specific therapy was performed in 35% of patients: 17% underwent microsurgical removal, and 18% underwent chemotherapy or radiotherapy.

*Conclusions.* This is one of the largest series confirming the safety and validity of the neuroendoscopic biopsy procedure. Complications were relatively low (about 13%), and they were all reversible. Neuroendoscopic biopsy provided meaningful pathological data in 90% of patients, making subsequent tumor therapy feasible. Cerebrospinal fluid pathways can be restored by ETV or septum pellucidotomy (65%) to control intracranial hypertension. In light of the results obtained, a neuroendoscopic biopsy should be considered a possible alternative to the stereotactic biopsy in the diagnosis and treatment of ventricular or paraventricular tumors. Furthermore, it could be the only surgical procedure necessary for the treatment of selected tumors. *(DOI: 10.3171/2011.1.FOCUS10326)*

**Key Words • intraventricular tumor • endoscopic biopsy • endoscopic third ventriculostomy • hydrocephalus**

The use of endoscopy in the biopsy of ventricular tumors was first reported by Fukushima[7] in 1978. Subsequently, the increasing experience with this technique has clearly shown its advantage in visualizing the tumors during removal of biopsy samples while simultaneously avoiding highly vascularized structures. In ventricular tumors causing obstructive hydrocephalus, neuroendoscopy has gained even more appeal as a first-choice procedure since it is possible to simultaneously perform tumor biopsy and ETV or septostomy.[8,17,21,24] The immediate relief of intracranial hypertension and the availability of specimens for a pathological diagnosis allow time for planning the most suitable treatment strategy based on histological diagnosis and CSF tumor markers.[14] In fact, in a subset of ventricular or paraventricular tumors, further

*Abbreviations used in this paper:* ETV = endoscopic third ventriculostomy; VP = ventriculoperitoneal.

surgical ablation is not required, and the endoscopic procedure may be the only surgical procedure necessary.[18]

Unfortunately, due to the infrequency of these lesions, comprising about 2% of all primary CNS tumors,[13,23] only limited series have been reported in the literature[2,3,6,16,26] and some questions remain unanswered. In light of this observation, the Section of Neuroendoscopy of the Italian Neurosurgical Society (SINCH) invited some expert members to review their own experience, gathering a sufficient number of cases for a wide analysis.[1]

## Methods

The data regarding neuroendoscopic procedures performed between 1997 and 2007 in 7 Italian centers, in which these procedures are routine, were retrospectively collected. Only neuroendoscopic procedures in which a biopsy sample was obtained from intraventricular and paraventricular tumors were analyzed. Patients affected by colloid cysts or benign intracranial cysts were excluded. All tumors were newly diagnosed, and histological diagnosis for deciding the specific treatment was necessary. A total of 60 patients (33 male and 27 female) were included from the 7 institutions involved (Bologna, Livorno, Naples, Padua, Roma, Reggio Calabria, and Treviso). Ages ranged from 5 to 78 years (median 48 years); 9 patients (15%) were children. All patients were symptomatic. Twenty patients (33%) presented with a classic intracranial hypertension syndrome, 2 of whom were lethargic on admission. The other patients presented with focal neurological signs (Table 1). Preoperative imaging consisted essentially of MR images to record ventricle diameters, tumor size, site, enhancement, and morphological characteristics. All tumors were associated with ventricular dilation, and had the following ranges in diameters: frontal horn, 13–75 mm (median 24 mm); Monro foramen, 5–20 mm (median 8 mm); and third ventricle, 9–25 mm (median 15 mm). The most frequent site of origin was the pineal region (38%), followed by the thalamic region (20%) and mesencephalon (18%). Forty-six tumors (77%) showed contrast enhancement, and 10 tumors (17%) were cystic. Six tumors (10%) were less than 10 mm in diameter, 21 (35%) were between 10 and 20 mm, and 29 (48%) were larger than 20 mm. The remaining 4 patients presented with diffuse lesions along the ventricle wall.

In all cases, a coronal or precoronal bur hole was chosen as the entry point. Depending on the location of the tumor and the ventricle size, a unilateral access (mainly right side) was performed in all cases except one in which it was bilateral. A flexible steerable fiberoptic scope (4-mm external diameter) was used in 40 cases, a rigid endoscope (6-mm external diameter) was used in 15 cases, and both rigid and fiberoptic scopes were used in 5 cases. Stereotactic guidance or neuronavigation was used in only 6 cases to identify the best entry point and trajectory of the rigid endoscope to the posterior part of the third ventricle. Biopsy forceps were used to obtain tumor specimens from different areas of the tumor. Intraoperative bleeding was classified as mild when partial blurred vision occurred, moderate when blurred vision lasted between 3 and 5 minutes, and severe when it persisted for more than 5 minutes.

**TABLE 1: Clinical findings at admission**

| Symptoms | No. of Patients |
|---|---|
| intracranial hypertension syndrome | 20 |
| ataxic gate | 13 |
| headache w/ papilledema | 8 |
| cognitive disorders | 7 |
| visual field deficits | 4 |
| ophthalmoplegia | 4 |
| Parinaud syndrome | 2 |
| hemiparesis | 1 |
| diabetes insipidus | 1 |

## Results

*Endoscopic Procedures*

In all, specimens from 60 patients were obtained. The total surgical time ranged from 15 to 180 minutes (median 57 minutes). Timing was prolonged when ETV or septostomy were required in addition to biopsy or when bleeding occurred.

At least 4 biopsy samples for each case (range 4–14 samples) were obtained. In 12 cases, frozen sections were obtained intraoperatively but were conclusive for diagnosis only in 6. In 38 patients (64%), obstructive hydrocephalus was present; triventricular hydrocephalus was noted in 32 and biventricular hydrocephalus in 6 patients.

In 32 patients (53%), ETV was successfully performed during the same endoscopic procedure to treat obstructive hydrocephalus (Fig. 1). Only 2 patients required a VP shunt shortly after the endoscopic procedure because ETV was not feasible. Relief of CSF pathway obstructions to control intracranial hypertension in 7 cases (12%) was obtained through septostomy with the aid of an Ommaya reservoir. Six of these patients were affected by tumors larger than 20 mm in diameter, bulging into the lateral ventricle from the thalamus. One of them was a lymphoma, which was subsequently treated using chemotherapy (Fig. 2).

In 21 procedures (35%), bleeding occurred and was more frequent in the 12 tumors (20%) that were larger than 20 mm in diameter. In 13 cases (22%), bleeding was mild, in 6 it was moderate, and only in 2 patients it was severe. In all cases, bleeding was stopped by cautery or continuous irrigation with Ringer lactate solution. It was never necessary to abandon the procedure because of bleeding.

In 90% of cases, a tissue diagnosis was obtained, and the diagnostic yield is listed in Table 2. A diagnosis of "nonspecific origin" tumor was made in only 5 patients (8%), most of whom had malignant tumors. In only 6 cases (10%), the tissue diagnosis remained inconclusive for insufficient material.

Following diagnosis of the biopsy specimen, 21 patients (35%) underwent a specific treatment regimen: 10 (17%) underwent surgical removal, while 11 (18%) (with pure germinoma or lymphoma) were treated using chemotherapy or radiotherapy alone.

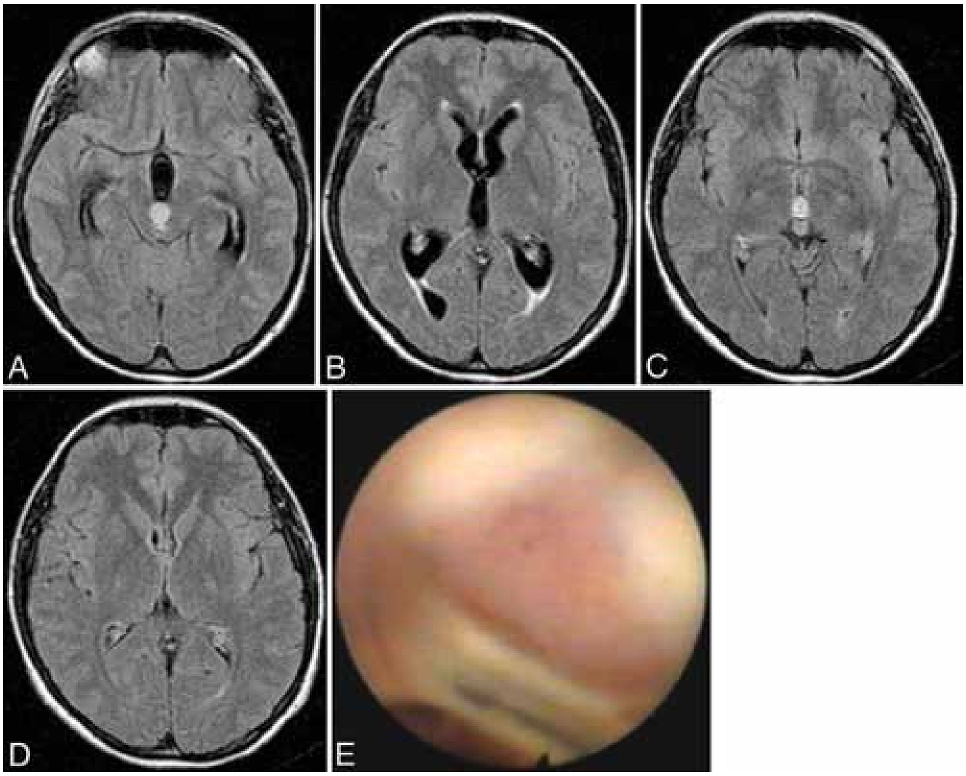


**Fig. 1.** Images obtained in a 33-year-old woman with a fibrillary astrocytoma associated with hydrocephalus. **A–D:** Axial FLAIR MR images. Preoperative images showing the tumor occluding the aqueduct **(A)** and hydrocephalus **(B)**. Images obtained 1 year after the biopsy and ETV, showing stable tumor **(C)** and reduction of ventricular diameters **(D)**. **E:** Endoscopic view of the tumor arising by the posterior commissure.

*Complications*

Due to the nature of the endoscopic procedure, no mortality or permanent morbidity was reported.

On postoperative imaging, 8 patients (13%) presented with intraventricular hemorrhagic complications due to endoscopic biopsy. In 4 (50%) of these, the hemorrhage was related to moderate bleeding ($p = 0.04$). All 8 tumors enhanced on MR imaging after administration of a contrast agent. Only 2 patients, presenting with a large and rich vascular tumor, were symptomatic and required medical therapy. In these patients, excessive biopsy sampling caused the tumor to hemorrhage. In the other 6 patients, hemorrhagic complications were not symptomatic and were noted only on postoperative images. In no case did clinically significant sequelae affect the patient's outcome.

Based on the discretion of the surgeon at the time of surgery, in 18 patients (30%) an external ventricular drain was placed for a few days, governed by the degree of intraventricular CSF flow. Other complications consisted of epilepsy in 2 patients, and hydrocephalus, meningitis, transient Parinaud syndrome, and intracerebral hematoma subsequent to ventricular puncture in 1 patient each.

## Discussion

Neuroendoscopy is an accepted and widely used technique for obtaining biopsy material from tumors located within the ventricular system. It also offers the possibility of using ETV for treatment of associated hydrocephalus.[9,11] Ventricular tumors represent a heterogeneous group in terms of histology and therapy and often present with common clinical history and radiological aspects. These lesions can be benign or malignant and may simulate malformative or infectious diseases. Although histological diagnosis can be suspected on the basis of clinical and neuroimaging findings, pathological investigation of tumor samples is mandatory, especially if a choice exists between surgical and nonsurgical treatment options.[2,13] Some tumors (for example, lymphoma or germinoma) are radiosensitive, and their surgical removal is excluded.[4,19] On the other hand, the most frequent type of clinical presentation is a syndrome from intracranial hypertension. This was present in 33% of our patients and was accompanied by ventricular dilation, even in tumors smaller than 10 mm in diameter, due to blockage of the CSF pathways with hydrocephalus or an entrapped ventricle. In these cases, the patients' clinical features ruled out the possibility of performing other therapies as an alternative to surgery, which is used for the diagnosis and relief of intracranial hypertension.[12] Some authors have proposed obtaining a histological diagnosis by stereotactic biopsy and then, on the basis of the histological findings, deciding whether to perform surgical removal, radiotherapy, or chemotherapy.[4,8,10] Large series of patients undergoing a stereotactic biopsy have reported a mortality rate of 0.7% with a 3.5% rate of permanent morbidity. The diagnostic accuracy is 91%, but it becomes remarkably lower in midline tumors with a higher incidence of complications.[15] The alternative for the treatment of hydrocephalus is VP shunting, a procedure that may play a

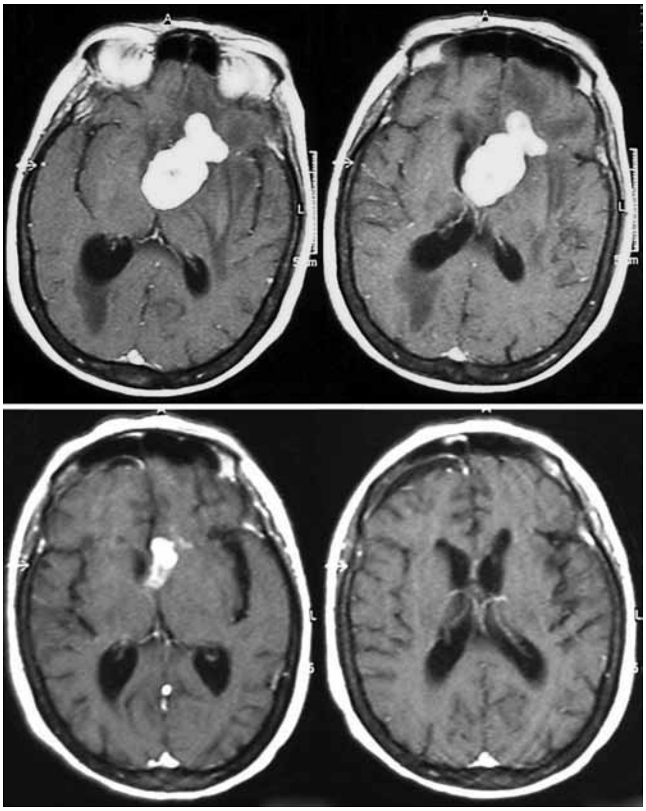

**Fig. 2.** Axial MR images obtained in a 65-year-old woman with a large intraventricular lymphoma. **Upper:** Preoperative images showing the lesion. **Lower:** Six months after the biopsy and septostomy, the images show remarkable tumor reduction during chemotherapy.

**TABLE 2: Histopathological diagnosis**

| Diagnosis | No. of Patients |
|---|---|
| low-grade glioma | 7 |
| high-grade glioma | 9 |
| pure germinoma | 9 |
| malignant teratoma | 1 |
| pineoblastoma | 2 |
| pineocytoma | 5 |
| craniopharyngioma | 4 |
| primitive neuroectodermal tumor | 3 |
| lymphoma | 6 |
| metastasis | 3 |
| nonspecific tumor | 5 |
| inconclusive | 6 |

role in dissemination of some tumors such as pinealoblastoma and germ cell tumors into the peritoneum.[24] For this reason, even today, microsurgical removal is considered the best therapeutic option in selected cases. However, due to the deep location of intra- and paraventricular tumors, it remains challenging and is fraught with potential complications, which may be functional and cognitive or even life-threatening.[12,25]

Over the past 10 years, the advances made in endoscopic technology have made it possible to suggest that the neuroendoscopic biopsy may represent an alternative strategy to stereotactic biopsy and microsurgery for obtaining a diagnosis.[1] At the same time, the neuroendoscope can harvest, under direct vision, biopsy specimens for defining histology and CSF samples for researching tumor markers. In fact, the CSF biochemical analysis to determine an accurate diagnosis of primary intracranial germ cell tumors is recommended.[14] This procedure is absolutely indicated even in conditions of hydrocephalus and intracranial hypertension, and makes it possible to restore CSF pathways by ETV or septostomy.[9,11] Endoscopic navigation to detect the lesion in patients with small ventricles is also possible using frameless neuronavigation.[1,18,22] Because intra- and paraventricular tumors account for just 2% of all intracranial tumors, studies regarding the effectiveness and safety of endoscopic biopsy have been limited to just a few series of patients.[3,6,13,16,20,26]

To the best of our knowledge, the present series, which does not include colloid cysts or other nontumoral lesions, is one of the largest series to evaluate retrospectively the validity of the endoscopic biopsy procedure. However, the analysis of the data recorded by the 7 Italian centers that boast the greatest experience in the past decade could be limited by the heterogeneity of the technique and the instruments used. Furthermore, our results could be representative of what would be expected by experts and not by neurosurgeons with less experience. Neuronavigation-guided endoscopy was helpful only in 6 selected cases to plan the best entry point and trajectory of the rigid endoscope to the posterior part of the third ventricle. Furthermore, neuronavigation guidance is still useful for intraoperative orientation, especially when there is impaired visualization or narrowing of the ventricles.[1,18,22] In our series, neuronavigation guidance was rarely used due to its need for a rigid endoscope. Therefore, a flexible steerable fiberoptic scope was more frequently used. A histological diagnosis was obtained in 90% of cases, a success rate similar to that reported by other authors.[2,3,6,16,20,26] In our experience, endoscopic biopsy had the same degree of accuracy as the stereotactic technique, but without the mortality and limited permanent morbidity of this procedure.[5,10,15] In our opinion, the superiority of endoscopic over stereotactic biopsy is due to the fact that it offers the possibility of simultaneously relieving the CSF pathways by ETV or septostomy, which was feasible in 65% of our cases. In comparison with open surgery, the neuroendoscopic biopsy is limited by the small size of the specimens harvested, which was the reason for diagnostic failure in 10% of the present series. Equally, neuroendoscopy has the possibility of controlling the tumor target and generally produces less bleeding. In our experience, bleeding was controllable, and hemorrhagic complications occurred only in 13% of patients, mainly in tumors larger than 20 mm in diameter that are presumably more malignant and more richly vascularized. In the future, we can predict that improved coagulation techniques (laser or radiofrequency) will make it possible to harvest the biopsy sample more safely and reduce the hemorrhagic complications. All the major complications were reversible and those minor ones, resolved by medical therapy, did not alter the natural history of the disease. Only 2 patients required a VP shunt shortly after the endoscopic procedure. Therefore, in our opinion the simultaneous biopsy does not increase the risk of ETV failure. The rationale behind the choice of performing neuroendoscopic biopsy is therefore not only to obtain a diagnosis, but also to control intracranial hypertension, enabling subsequent specific treatment. In fact, in our series, 18% of the tumors were treated by chemotherapy or radiotherapy alone. In lymphomas and pure germinomas, a regression of the tumor can be expected, restoring CSF pathways.[4,19] We believe that the histological diagnosis of tumors bulging into the lateral and third ventricles represents the first step in selecting patients for microsurgical removal, and that neuroendoscopy is a useful technique for obtaining tumor specimens and treating hydrocephalus in such cases.

## Conclusions

Our data confirm that the endoscopic biopsy, in comparison with open surgery and stereotactic biopsy, is a safe and minimally invasive procedure. Its diagnostic accuracy and capacity to restore CSF pathways by ETV, especially in the presence of obstructive hydrocephalus, offer the possibility of subsequent therapeutic options as an alternative or adjuvant to surgical therapy burdened by higher morbidity and mortality, even today.

### Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Gangemi, Godano, Longatti. Acquisition of data: Oppido, Cattani, Cipri, Mascari, Morace, Tosatto. Analysis and interpretation of data: Oppido, Morace. Drafting the article: Oppido. Critically revising the article: Fiorindi, Gangemi, Godano, Longatti. Reviewed final version of the manuscript and approved it for submission: Oppido, Godano, Longatti. Study supervision: Oppido, Benvenuti, Gangemi, Godano, Longatti, Morace.

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# Pineal region tumors: an optimal approach for simultaneous endoscopic third ventriculostomy and biopsy

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*Object.* Simultaneous endoscopic third ventriculostomy (ETV) and tumor biopsy is a widely accepted therapeutic and diagnostic procedure for patients with noncommunicating hydrocephalus secondary to a pineal region tumor. Multiple approaches have been advocated, including the use of a steerable fiberoptic or rigid lens endoscope via 1 or 2 trajectories. However, the optimal approach has not been established based on the individual anatomical characteristics of the patient.

*Methods.* A retrospective review of patients undergoing simultaneous ETV and tumor biopsy was undertaken. Preoperative MR images were examined to measure the width of the anterior third ventricle and maximal diameters of the tumor, Monro foramen (right), and massa intermedia. The distances between the tumor and massa intermedia, tumor and anterior commissure, midbrain and massa intermedia, and the dorsum sella and anterior commissure were also recorded. Single and dual trajectory approaches were compared using paired t-tests for each parameter.

*Results.* Over an 8-year interval, 15 patients underwent simultaneous ETV and tumor management. These patients ranged from 6 to 71 years of age (mean 36.7 years); 5 were younger than 18 years of age. Seven were treated using a dual trajectory approach, and 8 were treated using a single trajectory approach. All cases were completed without complications or the need for an additional CSF diversionary procedure within 6 months. The diagnostic yield at biopsy was 86.7%. There were no statistically significant differences between the single and dual trajectory groups for the measured parameters. However, the dual trajectory group demonstrated a larger anterior third ventricular diameter (1.43 vs 1.21 cm, $p = 0.29$). The single trajectory group trended toward a smaller tumor–anterior commissure interval (2.23 vs 2.51 cm, $p = 0.24$) and a larger dorsum sella–anterior commissure distance (1.67 vs 1.49 cm, $p = 0.28$).

*Conclusions.* These data confirm the safety and diagnostic efficacy of simultaneous ETV and biopsy for tumors of the pineal region. Although no statistically significant differences were seen in the authors' recorded measurements, several trends suggest a role for a tailored approach to selecting a single or dual trajectory approach when using a rigid endoscope. *(DOI: 10.3171/2011.2.FOCUS10301)*

**Key Words** • **pineal gland** • **pineal tumor** • **hydrocephalus** • **endoscopic third ventriculostomy** • **biopsy** • **neuroendoscopy**

Endoscopic biopsy has become a mainstay of the initial approach to tumors in the pineal region. Furthermore, approximately 90% of patients with these masses present with hydrocephalus requiring management.[16,22] Ventriculoperitoneal shunting or external ventricular drainage are options for management, but ETV offers a minimally invasive, safe method to treat hydrocephalus resulting from obstruction by the lesion. Endoscopic third ventriculostomy can be performed safely at the time of biopsy,[7] thus combining therapeutic and diagnostic functions and reducing the total number of procedures for the patient.[2,13,15,17] While simultaneous ETV and biopsy is now a common management strategy for tumors in the pineal region, an optimal surgical approach has not been established. In this report, we review our experience with simultaneous ETV and biopsy of tumors in the pineal region and consider potential factors favoring the selection of either a single or dual trajectory approach.

## Methods

Measurements defining the ventricular environment were studied in patients undergoing simultaneous ETV and biopsy of a pineal region mass. A retrospective review of patients between 2002 and 2010 was completed, and 15 patients were identified. Patient data including age, sex, date of surgery, diagnosis, and any associated complications

*Abbreviation used in this paper:* ETV = endoscopic third ventriculostomy.

were recorded. Complications were defined as the need for shunting in the 6-month period following surgery or any significant perioperative complication recorded in the electronic medical record. The institutional review board of Weill Cornell Medical College approved the review of clinical and radiographic records for this study.

The details of the surgical procedure and equipment used have been described previously.[12,19] In brief, stereotactic navigational guidance equipment (BrainLAB, Inc.) was used to optimize the planned trajectory and entry sites. Planning an optimal trajectory will reduce motion and torque on the endoscopic path due to sweeping motions of the scope with intraventricular navigation. A 0° or 30° rigid lens endoscope (Minop, B. Braun Aesculap) was used for ventricular cannulation. At the time of initial ventricular cannulation, CSF was collected for biochemical and cytological analysis. When performing simultaneous ETV and tumor biopsy, the ETV is performed prior to tumor biopsy. This order is advocated since the most pressing clinical condition (that is, noncommunicating hydrocephalus) should be definitively addressed prior to any potential visual obscuration by hemorrhage from tumor biopsy.

Following successful ETV, biopsy of the tumor was performed. If a single entry site was used, the 30°-angled lens was then rotated to achieve a posterior direction of view. If a separate anterior entry was used, a 0° lens was used to visualize the posterior third ventricle. In the event that the tumor was eccentric, the approach used a contralateral entry. Once the tumor was visualized, cupped biopsy forceps was used to sample the tumor. Sites of sampling that most likely represented pathological tissue, were relatively void of surface vascularity, and required as little torque as possible were chosen for biopsy. The small samples of tissue obtained with cupped forceps present challenges for accurate pathological interpretation, and every attempt was made to minimize artifact from cautery. Therefore, the use of coagulation on the tumor surface, as logical as that may seem, was avoided prior to sampling. The number of samples was governed by pathological interpretation, and no more tissue than absolutely necessary was taken in an effort to reduce intraventricular hemorrhage.

Magnetic resonance imaging examinations were performed using 1.5-T Signa HDx (8 patients) or 3T Signa HDxt (7 patients) imaging units (General Electric) utilizing a 16-channel-array head coil. In 3 patients, high-resolution coronal T2-weighted fast spin echo images were acquired using the following parameters: TR 6700 msec, TE 86 msec with a matrix of 512 × 512, and an interleaved 3-mm slice thickness. For 7 patients, 3D T1-weighted spoiled gradient echo (SPGR) images were also acquired following the intravenous administration of gadopentetate dimeglumine (Magnevist, Schering) using the following parameters: TR 8 msec, TE minimum (preset by MR imaging software), matrix 256 × 256, and 1.5-mm slice thickness. Measurements acquired on these sequences were confirmed using conventional multiplanar images (Fig. 1). In patients for whom the above images were not available, conventional sequences were used alone.

The diameter of the anterior third ventricle was used as an indicator of the degree of hydrocephalus. Other measurements included the maximal diameters of the tumor, Monro foramen (right), and massa intermedia, as well as the distances between the tumor and massa intermedia, tumor and anterior commissure, midbrain and massa intermedia, and the dorsum sella and anterior commissure. All measurements were performed by a board-certified neuroradiologist (A.J.T.) on a GE Advantage Workstation v4.3. Single and dual trajectory approaches were compared using paired t-tests for each parameter.

## Results

Patients ranged in age from 6 to 71 years (mean 36.7 years) at the time of surgery; there were 8 male and 7 fe-

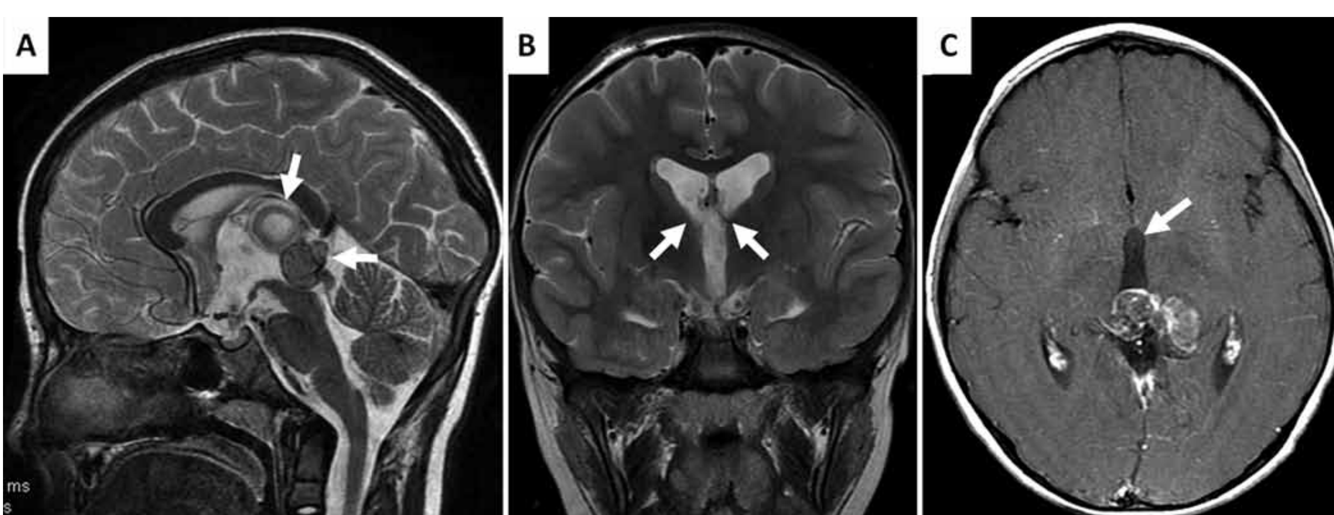


**Fig. 1.** Multiplanar MR images obtained in a 6-year-old boy presenting with headaches. **A:** Sagittal T2-weighted image demonstrating a complex mass in the pineal region *(arrows)*. **B:** Coronal T2-weighted image showing the maximal diameters of the Monro foramina *(arrows)*. **C:** Axial T1-weighted sequence showing the size of the anterior third ventricle, a measure of the degree of hydrocephalus *(arrow)*.

**TABLE 1: Demographics of patients undergoing simultaneous ETV and pineal mass biopsy**

| Case No. | Age (yrs), Sex | No. of Bur Holes | Diagnosis | Subsequent Resection | ETV Failure |
|---|---|---|---|---|---|
| 1 | 57, F | 1 | pineocytoma | yes | no |
| 2 | 59, F | 1 | pineal cyst | no | no |
| 3 | 46, F | 1 | pineoblastoma | yes | no |
| 4 | 17, M | 1 | pineal cyst | no | no |
| 5 | 35, F | 1 | indeterminate* | yes | no |
| 6 | 71, M | 1 | metastatic adenocarcinoma | no | no |
| 7 | 43, F | 2 | indeterminate* | yes | no |
| 8 | 18, M | 2 | germinoma | no | no |
| 9 | 30, F | 2 | pineal parenchymal tumor of intermediate differentiation | yes | no |
| 10 | 17, M | 2 | germinoma | no | no |
| 11 | 6, M | 1 | mature teratoma | yes | no |
| 12 | 15, M | 2 | germinoma | no | no |
| 13 | 25, F | 1 | pineocytoma | yes | no |
| 14 | 52, M | 2 | high-grade glioma | yes | no |
| 15 | 57, M | 2 | anaplastic astrocytoma | yes | no |

* Both patients with indeterminate biopsies were diagnosed with pineal parenchymal tumors of indeterminate differentiation after resection.

male patients. The most common diagnosis was germinoma, seen in 3 of the 15 patients. Endoscopic third ventriculostomy and biopsy was performed via 1 or 2 bur holes in 8 and 7 patients, respectively. The diagnostic yield at biopsy was 86.67% overall. There were no complications following surgery, and the ETV success rate was 100% in the first 6 months (Table 1).

There were no statistically significant differences between the single and dual trajectory groups for the measured parameters (Table 2). The dual trajectory group, however, trended toward a greater anterior third ventricular diameter (1.43 vs 1.21 cm, $p = 0.29$). The single trajectory group trended toward a smaller tumor–anterior commissure interval (2.23 vs 2.51 cm, $p = 0.24$) and a larger dorsum sella–anterior commissure distance (1.67 vs 1.49 cm, $p = 0.28$).

## Discussion

Tumors of the pineal region are rare, comprising less than 11% of all pediatric tumors.[6] In children, approximately 60% of pineal region tumors are of germ cell origin.[21] In these cases, the presence of $\alpha$-fetoprotein or $\beta$-human chorionic gonadotropin in serum or CSF is sufficient to diagnose malignant germ cell tumors without the need for biopsy.[11] When these markers are negative, tissue diagnosis becomes necessary, as different histological tumor types have variable responses to radiation therapy, chemotherapy, aggressive resection, or a combination of these treatment modalities.[3–5,10]

### *Biopsy and Initial Management*

Traditional methods of sampling pineal region masses include microsurgical and stereotactic biopsies. Both approaches result in increased morbidity for a variety of reasons including the vascularity of the pineal region.[22] Furthermore, recovery and operative time are longer in most cases accomplished via a microsurgical approach. Endoscopic biopsy has been widely described for the management of intraventricular tumors.[8,9,14,16,18,20] Endoscopy is now the preferred approach to biopsy in this region because it allows for direct visualization, simultaneous treatment of coexisting hydrocephalus, and is diagnostically sensitive[18,22] and minimally invasive.[1]

Since its description in 1997,[7] simultaneous ETV and biopsy has become an important procedure in the early management of pineal region masses with concurrent hydrocephalus, thus combining therapeutic and diagnostic functions and reducing the total number of procedures for the patient.[2,13,15,17] The combined procedure also al-

**TABLE 2: Parameter measurements of single and dual trajectory approaches to ETV and biopsy**

| Parameter | Measurement (cm) Single Trajectory (8 patients) | Measurement (cm) Dual Trajectory (7 patients) | p Value |
|---|---|---|---|
| anterior 3rd ventricle diameter | 1.21 | 1.43 | 0.29 |
| Monro foramen diameter (rt) | 0.61 | 0.69 | 0.61 |
| max massa intermedia diameter | 0.51 | 0.43 | 0.50 |
| max tumor diameter | 2.49 | 2.56 | 0.85 |
| tumor-massa distance | 0.81 | 0.90 | 0.61 |
| tumor–anterior commissure distance | 2.23 | 2.51 | 0.24 |
| midbrain-massa distance | 1.10 | 1.12 | 0.90 |
| dorsum sella–anterior commissure distance | 1.67 | 1.49 | 0.28 |

lows for sampling of CSF for tumor marker assays and examination for tumor dissemination. Multiple studies have demonstrated its safety, diagnostic efficacy, and lower morbidity and mortality compared with conventional approaches.[1,2,8,9,13,22] Our data support the results of earlier studies, in that our diagnostic efficacy exceeded 80% with no complications.

*Approaches to Simultaneous ETV and Biopsy*

While simultaneous ETV and biopsy is now a common management strategy for tumors in the pineal region, an optimal surgical approach has not been established. Different authors have reported the use of flexible fiberoptic or rigid lens endoscopes through 1 or 2 bur holes with varying degrees of success. Some have recommended the use of a flexible endoscope when combining ETV and biopsy to "avoid damage from moving a less-maneuverable rigid endoscope."[13] We advocate the use of a rigid lens endoscope because of its superior optical quality, image resolution, and greater size of compatible biopsy forceps. Larger biopsies have been shown to increase the diagnostic yield of the procedure without a measurable increase in morbidity or mortality.[1]

The optimal trajectories for ETV (coronal entry) and pineal region tumor biopsy (frontal-precoronal entry) are distinct, requiring that a single or dual entry site must be chosen if a rod lens endoscope is used. Many approaches are in use today, but it is advisable to choose a technique that best suits the individual patient based on the ventricular size, the relative position of the tumor, the dimension of the massa intermedia, and the surgical goal. It has been suggested that one use a single bur hole but that the bur hole be moved slightly more anteriorly than the typical approach to ETV to accommodate both procedures.[16] Yurtseven et al.[23] reported, "For tumors located in the pineal region… we prefer a burr hole just behind the hairy skin line in the midpupillary line," also with a rigid endoscope. Pople et al.,[15] on the other hand, used a dual approach, pointing out that "a separately placed more posterior burrhole was necessary to perform the third ventriculostomy."

Our experience has suggested that a single approach is best used when the tumor presents anterior to the massa intermedia, when the interthalamic adhesion is small, when the degree of ventriculomegaly is severe, or when the surgical intent is biopsy without consideration for total removal. If a single entry is used, a 30°-angled lens is recommended as a means to enhance the view off a linear axis. Alternatively, when tumors are recessed behind the massa intermedia, when the degree of ventriculomegaly is moderate or small, when tumors may be amenable to total removal (that is, those < 2 cm), or when the massa intermedia is large, 2 sites of entry are advocated. One should be optimal for the tumor biopsy/resection and the other for the ETV. These features are outlined in Table 3.

*Preoperative Planning and Radiographic Measurements*

We have recognized with time that these features may be measurable using preoperative imaging, thereby allowing for a more stereotyped approach to procedure selection. The measurements above are designed to delineate these and other parameters more objectively. While there are no significant differences between the 2 groups in our study, several trends suggest that this radiographically based approach to planning may be valuable.

**TABLE 3: Clinical features favoring a dual or single entry approach to simultaneous ETV and biopsy**

| Entry | Ventricular Size | Massa Intermedia | Tumor/Massa Relationship | Surgical Goal |
|---|---|---|---|---|
| single | large | small | anterior/inferior | biopsy |
| dual | small | large | posterior/superior | removal |

The use of 1 bur hole was associated with a smaller interval between the anterior commissure and the tumor, a parameter that describes the anterior extent of the tumor. Tumors extending farther forward were more accessible to the surgeon along a trajectory that was also suitable for ETV. The trend toward a greater dorsum sella–anterior commissure distance was also associated with a single trajectory approach and similarly describes a more accessible tumor.

There are several explanations for the absence of a significant difference between the single and dual trajectory groups. Given the range of patient ages and the variance we observed in the data, a more homogeneous group of patients may limit the variance and allow more minute differences to be detected between the groups. Similarly, a larger patient sample may ultimately allow the data to achieve statistical significance. It also may be that either approach is appropriate for any patient, and that the consequences of selecting a suboptimal approach are too minor to be observed clinically. Furthermore, there may be other metrics that differ between the groups that we have not considered, such as degree of intraventricular hemorrhage or forniceal contusion. Despite the lack of statistical significance in this small patient sample, the parameters we have described appear to be useful in determining whether the tumor can be targeted for biopsy along the same trajectory by which one would be able to access the floor of the third ventricle for ETV. Using measurements to choose a single or dual bur hole approach could aid clinical judgment and avoid the potential risk of introducing a second trajectory when it is unnecessary.

## Conclusions

Our data confirm the safety and diagnostic efficacy of simultaneous ETV and biopsy in the early management of a newly diagnosed pineal region mass. We have also demonstrated that, while it is not yet possible to recommend a set of standard criteria requiring one approach over another, several of our measurements showed trends toward a particular approach. Further evaluation of a larger patient cohort may allow us to make such recommendations.

**Disclosure**

Dr. Souweidane serves as a paid consultant and member of the NeuroEndoscopy Advisory Board for Aesculap.

Author contributions to the study and manuscript prepara-

tion include the following. Conception and design: Souweidane, Morgenstern, Osbun. Acquisition of data: Morgenstern, Osbun, Schwartz, Greenfield, Tsouris. Analysis and interpretation of data: Souweidane, Morgenstern, Osbun, Tsouris. Drafting the article: Souweidane, Morgenstern, Osbun, Tsouris. Critically revising the article: Souweidane, Morgenstern, Osbun, Tsouris. Reviewed final version of the manuscript and approved it for submission: Souweidane, Schwartz, Greenfield, Tsouris. Statistical analysis: Morgenstern. Administrative/technical/material support: Morgenstern. Study supervision: Souweidane.

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# Efficacy of simultaneous single-trajectory endoscopic tumor biopsy and endoscopic cerebrospinal fluid diversion procedures in intra- and paraventricular tumors

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*Object*. Intraventricular and paraventricular tumors resulting in hydrocephalus commonly require a CSF diversion procedure. A tumor biopsy can often be performed concurrently. Although the tissue samples obtained during endoscopic biopsy procedures are small, a diagnosis can be made in most cases. In the present study the authors analyzed the efficacy of concurrent endoscopic biopsy and CSF diversion procedures using a single bur hole and trajectory.

*Methods*. Eighty-seven patients with intraventricular and paraventricular tumors were treated with endoscopic biopsy and CSF diversion procedures using a rigid rod-lens endoscope or a rigid fiberscope during a 10-year period. All patients underwent a tumor biopsy and an endoscopic third ventriculostomy (ETV), aqueductal stenting (AS), or ventriculoperitoneal (VP) shunting, depending on the tumor location and site of obstruction. A single bur hole for both procedures was used in all patients.

*Results*. Among the 87 patients, the biopsy was diagnostic in 72 (83%) and merely suggestive in 7 (8%); in 8 patients (9%) the sample was nondiagnostic. Among the 22 patients who underwent an initial endoscopic biopsy and subsequent procedures, the specimen obtained at the second surgery was concordant with the initial endoscopic biopsy sample in 13 patients; it was somewhat similar in 4 patients. In the other 5 patients, either a microsurgical or stereotactic approach was used to correctly diagnose the pathology. Fifty-five patients were considered for endoscopic CSF diversion procedures; an ETV was performed in 52 patients and AS in 2. An ETV could not be performed in 3 patients for technical reasons. A VP shunt was inserted in 32 patients, with 25 undergoing shunt placement at the same time as the ETV and 7 at a later date. Significant bleeding was encountered in 3 patients during the tumor biopsy and in 1 patient during the ETV. The ETV failed in 1 patient during the follow-up, and a repeat ETV was required.

*Conclusions*. Endoscopic biopsy sampling and a concurrent CSF diversion procedure through a single bur hole and trajectory can be considered for intraventricular tumors. The overall success rates of 83% for the biopsy procedure and 86% for the ETV indicate that the procedures are beneficial in the majority of cases. A concordance rate of 75% was found in patients who underwent an initial biopsy procedure and a subsequent microsurgical approach for tumor excision. *(DOI: 10.3171/2011.1.FOCUS10295)*

**Key Words** • **endoscopic biopsy** • **endoscopic third ventriculostomy** • **hydrocephalus** • **neuroendoscopy** • **posterior third ventricular tumor**

A variety of pathologies are often encountered in paraventricular and intraventricular tumors. Their deep locations inside the brain often make these lesions difficult to access microsurgically. Because the tumors often obstruct the CSF pathways, they are accompanied by ventriculomegaly, requiring a CSF diversion procedure in either the preoperative or the postoperative period.

Given their proximity to the ventricular system, these tumors can often be accessed neuroendoscopically. In 1978 Fukushima[5] was one of the first to describe an endoscopic biopsy using a neurofiberscope for intraventricular tumors. Subsequent reports have described the efficacy of the endoscopic biopsy and simultaneous CSF diversion procedures, such as ETV and AS, for intraventricular tumors with hydrocephalus.[1,3,11,15,16,18,26] Reportedly, biopsies have yielded a diagnosis at a rate between 57% and 100%, while the success rates for ETV have been between 70% and 80%.[1,3,11,15,16,18,20,22,27,32] In the present study we ana-

*Abbreviations used in this paper:* AS = aqueductal stenting; ETV = endoscopic third ventriculostomy; VP = ventriculoperitoneal.

lyzed the results of biopsies and simultaneous CSF diversion procedures in patients who harbored intraventricular tumors with associated hydrocephalus.

## Methods

Patients with intra- and paraventricular tumors and tumor-like lesions who underwent endoscopic biopsy and CSF diversion procedures between 2000 and 2009 were included in the present study; those who underwent excision of the lesion were excluded. Preoperatively, the patients underwent either contrast-enhanced CT or MR imaging. An MR imaging study was performed in all patients being considered for an ETV. Additionally, patients with posterior third ventricular and tectal plate tumors underwent CSF flow studies to determine the obstruction to CSF flow by the tumor whenever necessary. An approach through a single bur hole was considered for the 2 procedures performed in all patients. The location of the bur hole was chosen based on the location of the tumor and the degree and type of associated hydrocephalus. A straight trajectory to the region of interest was preferred in all patients. The patients with posterior fossa tumors were considered for an endoscopic biopsy only if they required an ETV to control the hydrocephalus prior to the diagnostic surgery. Preoperative MR imaging in these patients demonstrated that the tumor was located in either the superior vermian region or the fourth ventricle with extension to the aqueductal inlet. A frontal occipital horn ratio of 0.38 or more was suggestive of hydrocephalus.[17] The considered CSF diversion procedures included ETV, AS, or VP shunt placement, based on the nature of the tumor and the type of hydrocephalus. Hydrocephalus due to obstruction at the posterior third ventricle or the aqueduct was considered for either ETV or AS, based on the safety and feasibility of the procedure and the patient's and family's wishes. Hydrocephalus due to obstruction at the fourth ventricle was considered for ETV. Ventriculoperitoneal shunt insertion was contemplated for hydrocephalus resulting from obstruction at the anterior third ventricle of the foramen of Monro. As the endoscope was used during surgery for the biopsy and was readily available, all shunts were placed under endoscopic visualization. Patients in whom the hydrocephalus was considered to be mild and asymptomatic were not initially considered for a CSF diversion procedure; however, if the patient became symptomatic later, a CSF diversion procedure was contemplated. In patients considered for an endoscopic CSF diversion procedure (ETV, aqueductoplasty, or endoscopic AS), the diversion procedure was performed first and the biopsy was undertaken later. In those considered for simultaneous VP shunt placement, the biopsy was conducted initially and the shunt was placed under endoscopic guidance through the same bur hole after the biopsy.

For both procedures, we primarily used a GAAB rigid lens endoscope (Karl Storz) with a working channel. If the foramen of Monro or the ventricles were inadequately dilated for the rigid scope, a GAAB pediatric rigid fiberscope was used. Additionally, for lesions in the superior vermian or the fourth ventricle region, we used a GAAB rigid fiberscope that could be safely accessed through the dilated aqueduct. After the bur hole was made, the ventricles were tapped with a 9 Fr peel-away sheath, and the CSF was collected for analysis including tumor markers when necessary. In patients in whom an ETV was indicated, the procedure was performed before the tumor biopsy. In patients who were candidates for simultaneous shunt insertion, the shunt was placed under endoscopic guidance in a dilated part of the lateral ventricle away from the tumor after the biopsy was performed.

For patients undergoing an ETV, the GAAB rigid endoscope was introduced into the third ventricle and the tuber cinereum was identified. The fenestration was made with a 3 Fr or a 4 Fr Fogarty catheter in front of the mammillary bodies and was subsequently enlarged by dilating the balloon. By advancing the endoscope, we observed the basal cisterns; any second membrane evident at surgery was fenestrated. For the patients undergoing an aqueductal reconstruction procedure, the aqueduct was dilated with a 3 Fr Fogarty catheter and the fourth ventricle inlet was visualized. In patients considered for AS, excessive dilation of the aqueduct was avoided. We used a freestanding 4-cm-long aqueductal stent (G. Surgiwear Ltd.) introduced through the endoscope's working channel for this purpose. After choosing the most dilated part of the ventricle, the ventricular catheter was placed using a peel-away sheath technique under endoscopic guidance.

During the endoscopic biopsy, several tissue samples were obtained from the most accessible part of the tumor by using either 2 × 2–mm cupped biopsy forceps (rigid rod-lens scope) or 1 × 2–mm biopsy forceps (rigid fiberscope) under direct endoscopic vision. Prebiopsy coagulation of the tumor surface was avoided unless the tumor surface appeared unduly vascular. Every attempt was made to obtain multiple samples (minimum 3, usually 6–10 bits) from different locations of the tumor and from both its surface and its depth. Mild bleeding from the tumor surface was usually controlled with irrigation. Samples were sent for histopathological evaluation. During the initial part of the study, the samples were sent for both preliminary evaluation (either smear section or frozen section) and permanent histopathological evaluation, whereas during the latter part of the study, all sample bits were sent for permanent histopathological evaluation only. Hemostasis was achieved with the help of coagulation and continuous irrigation with lactated Ringer solution at body temperature. Bleeding during surgery was classified as minor (mild expected oozing controlled with irrigation and coagulation, requiring no more than 5 minutes of operative time to control), moderate (significant oozing controlled with irrigation and coagulation, requiring more than 5 minutes to control), and severe (significant bleeding that required placement of an external drain, procedure may or may not be abandoned).

All patients underwent follow-up CT or MR imaging on the 1st postoperative day to assess for any tumor bed or intraventricular hemorrhage, the degree of pneumocephalus, and the position of the stent or ventricular catheter. Patients who did not undergo shunt placement during the initial surgery were carefully observed for any signs of progressive hydrocephalus, and if required, a VP shunt was placed through another bur hole in the parietal region.

Histopathological reports were evaluated, and the biopsy samples were classified as diagnostic, suggestive, and nondiagnostic. Diagnostic specimens demonstrated either a classic diagnostic pattern or had evidence from which a diagnosis could be made under standard conditions. The suggestive specimens had evidence of a pathological process but did not meet the criteria required for a definitive diagnostic pattern (for example, a chronic inflammatory pattern in a patient with tuberculous pathology). The nondiagnostic tissue specimens demonstrated normal tissue patterns or were from adjacent regions that suggested the presence of a pathological process but did not include samples from which to diagnose a disorder. Immunohistochemistry was performed when necessary to establish a diagnosis. The final diagnosis was made by integrating and correlating the clinical and radiological picture with the overall pathological diagnosis.

Patients underwent further treatment depending on their histopathological evaluation. In those with a negative biopsy or inadequate results, a repeat endoscopic biopsy or a stereotactic biopsy was considered. If microsurgical removal was necessary, it was considered during the postoperative period or at follow-up.

The follow-up period for the ETV varied between 12 months and 4 years, with a mean of 23 months. Computed tomography and MR imaging studies were performed at the follow-up to evaluate the ventricle size and the status of the tumor.

## Results

Of the 87 patients with intra- and paraventricular tumors and tumor-like lesions who underwent endoscopic biopsy and CSF diversion procedures during the study period, 32 were in the pediatric age group, with 5 younger than 1 year (Table 1). Tumors were located in the region of the posterior third ventricle in 41 patients, in the pineal region in 30 and in the tectum in 11. Six patients had brainstem tumors, while 11 had tumors situated in the region of the foramen of Monro or in the lateral ventricle. Three patients had asymmetrical biventricular hydrocephalus, with one of them demonstrating unilateral hydrocephalus. In all 87 patients, endoscopic visualization of the tumor and biopsy could be performed (Table 2). In 5 patients the biopsy samples were sent for both intraoperative evaluation (either frozen section or smear preparation, depending on the institution) and permanent evaluation, and the other 82 patients had samples sent only for permanent evaluation.

The initial endoscopic biopsy was diagnostic in 72 patients (83%), suggestive of the pathology in 7 (8%), and nondiagnostic in 8 (9%). Initial biopsy results are listed in Table 3. The diagnostic yield as compared with the location of the tumor is described in Table 4 .

Among the 87 patients, an ETV was considered in 55; it was successfully performed in 52 (Table 5). In 2 patients the procedure could not be performed due to abnormal findings observed intraoperatively (tumor growth or inadequate visualization), and in another it was abandoned because of excessive bleeding. Two patients underwent AS. A septostomy was performed in 15 patients during the endoscopic exploration either for asymmetrical hydrocephalus or for better tumor visualization.

Twenty-three patients were initially considered for VP shunt placement during the tumor biopsy. Two other patients in whom an ETV could not be completed because of anatomical abnormalities underwent shunt placement during the tumor biopsy. In 7 patients shunt placement was performed during the postoperative period; in 6 of them the shunt was required because of symptomatic hydrocephalus. Another patient with significant bleeding who could not undergo an ETV also required a shunt. One patient with mild ventriculomegaly did not require a CSF diversion procedure.

Of the 52 patients in whom an ETV could be successfully performed, the procedure was successful in 45 (85%). Of the 7 unsuccessful ETVs, 6 failed in the early postoperative period (< 6 weeks) and 1 failed 2 years after the initial procedure. The early failures were treated with

**TABLE 1: Age distribution and tumor location in 87 patients treated with CSF diversion procedures and endoscopic biopsy**

| Parameter | No. |
|---|---|
| age in yrs | |
| 0–1 | 5 |
| 1–2 | 2 |
| 3–18 | 25 |
| >18 | 55 |
| tumor location (includes multiple lesions) | |
| pineal region | 30 |
| tectal | 11 |
| hypothalamic | 5 |
| thalamic | 13 |
| suprasellar | 7 |
| brainstem | 5 |
| foramen of Monro | 6 |
| lat ventricle | 5 |
| other | 10 |

**TABLE 2: Tumor biopsy procedure and outcome in 87 patients**

| Parameter | No. (%) |
|---|---|
| tumor biopsy procedure | |
| successful | 87 |
| frozen/smear section & permanent section* | 5 |
| permanent section only | 82 |
| tumor biopsy outcome | |
| diagnostic | 72 (83) |
| suggestive | 7 (8) |
| nondiagnostic | 8 (9) |
| consistency btwn endoscopic biopsy & subsequent op | |
| consistent | 12 |
| similar | 5 |
| inconsistent | 5 |

* Consistency between frozen and permanent section was 100%.

**TABLE 3: Initial pathology in 87 patients with intra- and paraventricular tumors***

| Tumor Type | No. of Cases |
|---|---|
| glial | 41 |
| low-grade astrocytoma | 15 |
| AA | 4 |
| malignant astrocytoma | 6 |
| glioblastoma multiforme | 8 |
| anaplastic oligodendroglioma | 1 |
| anaplastic ependymoma | 1 |
| PXA | 1 |
| subependymal giant cell astrocytoma | 1 |
| subependymoma | 1 |
| pilomyxoid astrocytoma | 2 |
| astrocytoma, grade uncertain | 1 |
| pineal region | 23 |
| pinealocytoma | 4 |
| pinealoblastoma | 14 |
| embryonal cell carcinoma | 1 |
| germinoma | 4 |
| tubercular granuloma | 3 |
| tuberculoma | 2 |
| consistent w/ tuberculosis | 1 |
| PNET | 3 |
| medulloblastoma | 3 |
| miscellaneous | 9 |
| choroid plexus papilloma | 1 |
| craniopharyngioma | 3 |
| cavernous angioma | 1 |
| metastatic lesion | 1 |
| hamartoma | 1 |
| hematoma | 1 |
| lymphoma | 1 |
| inconclusive | 8 |

* AA = anaplastic astrocytoma; PNET = primitive neuroectodermal tumor; PXA = pleomorphic xanthoastrocytoma.

the insertion of a VP shunt, and the sole child with a late failure underwent a repeat ETV, which was successful. The 2 patients who underwent AS had good relief of their hydrocephalus symptoms.

Twenty-two patients subsequently underwent 24 repeat procedures (Table 6). The initial repeat procedures involved endoscopic biopsy in 2 patients, microsurgery and tumor excision in 18, and stereotactic biopsy in 2. Two patients required a third procedure for a definitive diagnosis; one of them who underwent a diagnostic stereotactic procedure had an inconclusive result and thus underwent microsurgery for a definitive diagnosis. Another patient underwent a repeat endoscopic biopsy that was still inconclusive, and thus a microsurgical approach was performed for a definitive diagnosis.

In the 5 patients with both intraoperative and permanent evaluations, the diagnosis was consistent between the frozen section and the permanent histopathological evaluation (Table 2). In the 22 patients who underwent an initial endoscopic biopsy and subsequent procedures, the diagnosis was consistent in 12 and somewhat similar in 4. In 6 other patients, either the microsurgical or the stereotactic approach correctly diagnosed the pathology; this includes the 2 patients who had to undergo a third procedure for diagnosis.

Of the 55 patients considered for ETV, 1 had significant bleeding that required the procedure to be abandoned and 2 had postoperative CSF leakage (Table 7). Mild forniceal surface contusion, injury to the massa intermedia, and ventriculitis were the other significant complications. During the tumor biopsy, bleeding was encountered in 15

**TABLE 4: Location of the tumor and initial diagnostic yield***

| Location | Total | Conclusive | Suggestive | Inconclusive |
|---|---|---|---|---|
| pineal region | 30 | 25 | 3 | 2 |
| tectal | 11 | 10 | 0 | 1 |
| hypothalamic | 5 | 5 | 0 | 0 |
| thalamic | 13 | 11 | 1 | 1 |
| suprasellar | 7 | 6 | 0 | 1 |
| brainstem | 5 | 5 | 0 | 0 |
| foramen of Monro | 6 | 4 | 2 | 0 |
| lat ventricle | 5 | 5 | 0 | 0 |
| cerebellar/superior vermian | 3 | 1 | 0 | 2 |
| pst fossa/intra–4th ventricular | 4 | 3 | 0 | 1 |
| caudate | 2 | 1 | 1 | 0 |

* pst = posterior.

**TABLE 5: Cerebrospinal fluid diversion procedure and outcome in 87 patients***

| Procedure | No. |
|---|---|
| CSF diversion | 86 |
| ETV considered | 55 |
| ETV performed | 52 |
| technical difficulties | 3 |
| ETV not performed | 2 |
| ETV abandoned | 1 |
| AS | 2 |
| VP shunt placement | 29* |
| during the tumor biopsy | 23 |
| at later date | 6 |
| ETV outcome | 52 |
| successful | 45 |
| failure | 7 |
| early | 6 |
| late | 1 |

* Three patients who could not undergo ETV also underwent VP shunt placement, 2 at the time of tumor biopsy and 1 at follow-up.

TABLE 6: Correlation in pathological diagnosis among the initial and endoscopic biopsy and subsequent surgery*

| Location | Initial Endoscopic Biopsy | Subsequent Pathology | Type of Op | Comment |
|---|---|---|---|---|
| pst-3rd ventricle | pinealocytoma | pinealocytoma Grade II | MS | concurrent |
| rt lat ventricle | choroid plexus papilloma | choroid plexus papilloma | MS | concurrent |
| pst-3rd ventricle | possible low-grade astrocytoma | astrocytoma Grade II | MS | suggestive |
| hypothalamus | low-grade astrocytoma | pilomyxoid astrocytoma | MS | concurrent |
| septal/suprasellar | undetermined | germinoma | endo & MS | inconclusive |
| pst-3rd ventricle | pinealoblastoma | pleomorphic pinealocytoma | MS | suggestive |
| superior vermis | hematoma | inflammatory pathology | MS | inconclusive |
| pst-3rd ventricle | inconclusive | epidermoid | stereo & MS | inconclusive |
| pst-3rd ventricle | AA | AA (WHO III) | MS | concurrent |
| pst-3rd ventricle | pinealocytoma (WHO II) | pinealocytoma (WHO II) | MS | concurrent |
| bilat thalamic | inconclusive | low-grade glioma (WHO II) | stereo | inconclusive |
| pst-3rd ventricle | pinealocytoma | pinealocytoma | MS | concurrent |
| superior vermis | cyst wall, possible gliosis | low-grade glioma | MS | inconclusive |
| pst-3rd ventricle | pinealocytoma | pinealocytoma | MS | concurrent |
| superior vermis | medulloblastoma | medulloblastoma | MS | concurrent |
| ant-3rd ventricle | astrocytoma Grade I–II | astrocytoma Grade II–III | MS | suggestive |
| pst-3rd ventricle | tumor edge | pinealoblastoma | MS | inconclusive |
| pst-3rd ventricle | PNET | glioblastoma | MS | suggestive |
| pst-3rd ventricle | pinealoblastoma | pinealoblastoma | MS | concurrent |
| intra-3rd ventricle | craniopharyngioma | craniopharyngioma | MS | concurrent |
| septum, lat vent wall | PXA | PXA | endo | concurrent |
| pst-3rd ventricle | cavernous angioma | cavernous angioma | MS | concurrent |

* ant = anterior; concurrent = initial biopsy concurrent with final biopsy; endo = endoscopy; inconclusive = inconclusive at initial biopsy; MS = microsurgery; stereo = stereotaxy; suggestive = initial biopsy suggestive of final biopsy; vent = ventricular.

patients—mild in 12, moderate in 2, and severe in 1 requiring placement of an external ventricular drain. There were 3 deaths, caused by pulmonary embolism, ventriculitis, and aspiration pneumonia in 1 case each.

## Discussion

Endoscopes offer a distinct advantage over conventional microscopes in visualizing and approaching deep-seated tumors adjacent to the ventricles and the CSF spaces. The hydrocephalus resulting from obstruction of the CSF pathways is advantageous in that it dilates the ventricles, which facilitates safe and easy navigation of the endoscopes without causing injury to the adjacent structures.

*Advantages of Endoscopic Biopsy*

Endoscopy offers direct visualization of the intraventricular anatomy and allows precise biopsies of the most suspect area of the lesion, which has been reported to improve diagnostic accuracy. Further, as the procedure is performed under direction vision, biopsies from areas with an overlying blood vessel can be avoided, and areas with increased vascularity can be precoagulated to reduce bleeding during the procedure. Moreover, the CSF collected at the time of surgery can be evaluated for tumor markers, which can often be useful in cases of nondiagnostic biopsy. The greatest advantage of the endoscopic biopsy lies in the fact that a simultaneous CSF diversion procedure can be performed in indicated patients, and thus a second surgery can be avoided. Though ETV has been the most common CSF diversion procedure, septos-

TABLE 7: Complications in 87 patients who underwent endoscopic biopsy and CSF diversion procedures

| Complication | No. of Cases |
|---|---|
| bleeding | |
| during tumor biopsy | 15 |
| mild | 12 |
| moderate | 2 |
| severe | 1 |
| during ETV | 1 |
| severe | 1 |
| forniceal contusion | 8 |
| mild | 7 |
| significant | 1 |
| injury to massa intermedia | 1 |
| ventriculitis | 2 |
| death | 3 |
| pulmonary embolism | 1 |
| ventriculitis | 1 |
| aspiration pneumonia | 1 |

tomy, placement of an aqueductal stent, and VP shunt insertion have also been considered.[1,3,11,13,15,16,18,31,32]

*Success Rate for Endoscopic Biopsy*

Several published reports have documented the efficacy of endoscopic tumor biopsies in pediatric and adult populations. The overall success rates for tumors in all locations in major series have varied between 61% and 100%. Fiorindi and Longatti,[4] on compiling 206 reported cases of endoscopic tumor biopsies in 9 series, reported an overall diagnostic yield of 88%. Tirakotai et al.[29] reported a 100% diagnostic yield in 29 patients who underwent endoscopic biopsies. Similarly, Souweidane[26] reported a diagnostic yield of 96% in a series of 26 patients, with the biopsy abandoned in only 1 patient because of bleeding. Similar diagnostic yields have been reported by others;[16,25] however, a slightly lower success rate has been reported by still others. Macarthur et al.[11] had an overall success rate of 61% in 28 biopsies. The overall success rates in other reports have ranged between 69% and 76%.[1,3,15] In the present report we had a definitive diagnostic rate of 83%, and if we include the 7 patients in whom the biopsy suggested a pathology to an extent sufficient for consideration of further management, the overall positive diagnostic rate was 91%.

*Considerations in Achieving a High Diagnostic Yield*

*Rigid Versus Flexible Endoscopes*. On analysis of the literature, we found a correlation between the use of a flexible scope and a relatively higher nondiagnostic rate; higher success rates were uniformly demonstrated with the use of rigid endoscopes. Rigid endoscopes appear to improve the diagnostic rate in several different ways. They permit the passage of larger-diameter biopsy forceps, which procure larger sample sizes. Additionally, an improved picture quality with better visualization allows one to obtain samples from various regions of the exposed tumor surface. In a prior study, the diagnostic rate significantly improved with rigid scopes (76%) as compared with steerable scopes (43%).[3] Similar observations were also reported by Ahn and Goumnerova[1]: a 45% diagnostic biopsy using flexible scopes as compared with 81% using rigid scopes.

In the present study we preferentially used a rigid rod-lens endoscope. The superior optics and excellent illumination together with the ability to obtain large biopsy samples were the primary factors in choosing the rigid endoscope over a flexible one. We precisely planned the position of the bur hole to obtain a straight trajectory to the lesion. The location of the bur hole for pineal region tumors was decided after identifying the midpoint of the anterior margin of the tumor and the site of the third ventriculostomy and extrapolating the line along the posterior margin of the foramen of Monro to the calvaria. Considerations in placing the bur hole to access lesions in the third ventricle and the para–third ventricular region included the size of the foramen of Monro and the site of the tumor with the bur hole situated on the opposite side of the lesion to access it via a straight trajectory. In the patients with a relatively nondilated foramen of Monro, we preferred to use a rigid fiberscope rather than a flexible scope because of its better orientation and relatively large diameter of biopsy forceps.

*Location of the Tumor and Diagnostic Yield*. Previous reports have also described a relation between the location of the tumor and a successful biopsy. Ahn and Goumnerova[1] documented 100% success rates for lateral ventricular lesions and 87.5% for pineal lesion locations, while the diagnostic accuracy decreased to 57% for thalamic and 25% for tectal lesions. Pineal region tumors have been associated with a higher diagnostic yield. In one of our previous communications, we reported a diagnostic yield of 100% for posterior third ventricular lesions in 23 patients in whom a biopsy could be successfully performed.[21] Similarly, a 94% positive diagnosis rate using both flexible and rigid endoscopes was quoted by Pople et al.[18]

In the present study, we experienced a high failure rate for superior vermian biopsies. Though the consideration of a concurrent biopsy during ETV did not change the overall management protocol in these patients, the biopsy was aimed at providing a tissue diagnosis before the definitive surgery for treating the tumor, which often helps in planning the overall management and assists families in the decision process. Performing a biopsy in conjunction with an ETV did not add much to the overall operative time or morbidity. Although it is difficult to conclude the exact reason for the negative biopsies in a limited number of cases, we believe that they were most likely due to the tumor location and the limited access to the region. The superior vermian lesions that were biopsied endoscopically impinged either on the superior velum region or into the superior fourth ventricle. These lesions were biopsied through the trans–third ventricle aqueductal corridor by using the thinner GAAB rigid fiberscope with a smaller-cup biopsy forceps. A similar observation was made by Depreitere et al.,[3] who noted that there was a poor diagnostic yield associated with posterior fossa tumors possibly given the use of steerable endoscopes. For pineal region tumors, we had a conclusive biopsy rate of 83% with an additional 10% suggestive of the lesion.

*Frozen Section or Permanent Section?* Conventionally, during the biopsy, tumor samples are initially sent for either frozen section or squash preparation, and a preliminary report is obtained from the pathologist prior to closing. During the endoscopic biopsy, obtained samples are considerably smaller than the tissue specimens obtained during microsurgery. The tissue samples obtained in an endoscopic biopsy are usually 1 × 1 or 2 × 2 mm in diameter, depending on the endoscope and biopsy forceps used during the procedure. Considering this, in the present series, in only 5 patients were specimens sent for both frozen section or squash preparation and permanent section. We followed this course with the aim of providing the neuropathologist with all the specimens obtained during the biopsy for a definitive histopathological analysis. Further, as in endoscopic biopsies, samples were obtained under direct vision; we believe that there is a smaller chance of misidentifying the lesion if it is well visualized at surgery. In the 5 patients in whom both frozen or smear sections and permanent sections were evaluated, there was a 100% correlation between the 2 techniques. Though in the present study we cannot substantiate our philosophy of not sending for an intraoperative diagnosis, we believe that in patients with a smaller biopsy specimen, it is not unreasonable to preserve the entire obtained specimen for permanent section.

*Intraoperative Guidance and Improved Visualization*. Intraoperative image guidance has been used during the biopsy and CSF diversion procedure[13,19,24–26] and is especially recommended in patients without hydrocephalus to improve accuracy and minimize brain trauma.[24] Others have used frameless stereotactic guidance exclusively for trajectory planning and for optimizing ventricular cannulation.[26] In a previous report, a 100% diagnostic sampling was achieved in 12 patients who had intraventricular masses without any significant ventriculomegaly.

Two recent reports have highlighted improving the diagnostic yield in tumor biopsies. Husain et al.[6] documented a higher incidence of a positive yield through a cytohistological approach in endoscopic biopsies. The diagnostic yield improved from 77.4% to 93.5% by combining cytological evaluation of the tumor irrigation fluid obtained during the biopsy with the conventional histological approach. In another interesting report, Tamura et al.[28] used 5-aminolevulinic acid (5-ALA)–induced protoporphyrin IX fluorescence imaging system to visualize a malignant glioma in the third ventricle prior to biopsy.

*Concordance Between the Initial Biopsy and Subsequent Biopsies*

In the present series, a subsequent surgical approach was undertaken in 22 patients (25%) for either a repeat biopsy or tumor decompression. Among these patients, a repeat biopsy or surgery was performed in 6, as the initial biopsy was nondiagnostic. Thus, in 16 patients both the initial endoscopic surgery and the subsequent surgery revealed a diagnosis. This result enabled us to analyze the correlation between the endoscopic biopsy and the biopsy obtained during the subsequent surgery. Among these 16 patients, the subsequent diagnosis matched the initial diagnosis in 12 (concordance rate of 75%). In the remaining 4 patients, the subsequent diagnosis at microsurgery revealed a similar, though not exact, picture. Evaluation of a tissue sample that was larger or from a different region probably led to the refined diagnosis during the microsurgical approach. Concordance rates have been found to vary from 83% (5 of 6 patients in Depreitere et al.[3]) to 80% (4 of 5 patients in O'Brien et al.[15]).

*Management of Hydrocephalus*

Associated hydrocephalus in patients with intraventricular tumors depends on the location of the tumor and the degree of obstruction. Pineal and tectal tumors are more likely to cause hydrocephalus given their strategic location and proximity to the aqueduct, whereas tumors located at the foramen of Monro and lateral ventricles are more likely to cause dilation of one, both, or a segment of the lateral ventricles. Interventricular septostomy can permit communication of trapped lateral ventricles with the rest of the ventricular system, and thus relieve the hydrocephalus. Septostomy is a relatively safe procedure and has been successfully used in tumor-associated hydrocephalus.[1,3,11,16,27] The placement of aqueductal stents has been infrequently described, especially in tumors in the region of the aqueduct.[16]

*Efficacy of ETV*

There are several well-documented reports mentioning the efficacy of ETV in obstructive hydrocephalus associated with tumor. Ray et al.[20] reported a success rate of 70% in 43 patients. Similar reports have been published by others.[15,22] In another study, Macarthur et al.[11] had a short-term success rate of 95% and long-term rate of 83% for ETV in patients with tumors. The early failure in third ventriculostomy has been attributed to nonabsorption of the CSF at the arachnoid granulation. Delayed failure in ETV has been commonly attributed to gliosis or ependymal or arachnoid scarring involving the third ventricular floor.[12] However, authors of 2 recent reports have described stoma obstruction by a tumor growth or seedling.[10,14] In the present study, in patients in whom ETV could be performed satisfactorily, the long-term success rate was 86%. The success rate drops to 81% if the technical failures are included in the calculation.

*Dual Port or Single Port?*

A single bur hole approach has been found to be adequate in most studies when the tumor is located in the anterior third ventricle or lateral ventricle. However, as the trajectories for the third ventricle and the biopsy are different for tumors located in the posterior third ventricle or the periaqueductal region, some consider using 2 bur holes, 1 exclusively for the tumor biopsy and the other for the third ventriculostomy.[30,32] Most authors using a steerable endoscope favor a single bur hole for both the ETV and the tumor biopsy.[3,7,15,27] In a previous report, Macarthur et al.[11] considered 2 bur holes to be useful in only 2 of 87 patients; they suggested that 2 bur holes should not be required as a routine. In the present series, we predominantly used a rigid rod-lens scope for both procedures. In patients with a narrow foramen of Monro or a mildly dilated third ventricle, we preferentially used the GAAB rigid fiberscope, which has a narrower diameter than the rod-lens scope without sacrificing much of the picture quality. In another report, Chernov et al.[2] have advocated the use of a dual port system for bilateral intraventricular access with continuous irrigation, which can permit uninterrupted use of the working channel of the fiberscope used for the biopsy. With the use of the rigid endoscope, we did not encounter any concerns in terms of irrigation, as the ventricles can be well irrigated through the additional channel and the tumor biopsy can be obtained through the instrument channel.

*Are Certain Parts of the Brain More Risky for Tumor Biopsy?*

It is generally thought that lesions in the thalamus or basal ganglionic region can be more difficult to biopsy and may be associated with an increased risk unless the ependymal surface is violated by the tumor. However, in our 87 patients, we did not encounter any increased complications at any specific location. The incidence of clinically significant hemorrhage after tumor biopsy was reported as 3.5% in a series of 86 patients with the procedure aborted in 2 (2.3%).[8] We had 3 patients with significant bleeding (moderate to severe), and the bleeding site was located in the pineal region in 2 of these patients. One of the patients, who harbored a cavernoma, had significant tumor bleeding during the surgery. The other patient, who had a pinealocytoma, had moderate bleeding during the surgery, and although it subsided with irrigation, a tumor bed hematoma resulted. This patient required repeat surgery for tumor excision and hematoma evacuation, but she died a week later as a result of aspiration pneumonia.

During the tumor biopsy, mild bleeding is expected from the tumor margins. Most of the bleeding in the present study was mild and was well controlled with irrigation and cauterization. Prebiopsy cauterization of the tumor surface would obviously have reduced the incidence of bleeding during surgery; however, it might also have led to cautery artifacts of the biopsy samples, and thus reduced the overall diagnostic yield.

We observed forniceal contusion in 8 patients, which was mild in 7 and significant in 1. This finding may be related to our protocol of using a rigid rod-lens scope and attempting to navigate anteriorly for the third ventriculostomy and the subsequent posterior trajectory for the tumor biopsy. However, the forniceal contusions did not result in clinically appreciable memory deficits. Considering this and the fact that the diagnostic yield with flexible scopes was lower than that with rigid scopes, we have not modified our practice of using the rigid scope as our initial choice in most patients with a dilated foramen. Note, however, that we did consider using a thinner-diameter rigid fiberscope in patients with a narrow or normally sized foramen or in whom a biopsy from the aqueductal inlet or superior vermian region is required.

*Sequence for ETV and Tumor Biopsy*

There has been considerable discussion in the literature regarding prioritization of the procedures during a tumor biopsy and ETV. Obtaining a tumor biopsy before the third ventriculostomy has been supported by some to minimize dissemination of the tumor cells.[32] Most others obtain a tumor biopsy subsequent to the ETV, as mild bleeding during the biopsy can obliterate the landmarks for a safe fenestration in the third ventricular floor.[1,3,15,16] We have performed all tumor biopsies after the ETV to reduce the risk of abandoning the ETV as a result of bleeding during the tumor biopsy. However, in patients undergoing VP shunt placement during the same surgery, the shunt insertion was performed under endoscopic guidance after the tumor biopsy.

Although there have been some concerns regarding possible tumor dissemination with concurrent endoscopic biopsy and ETV, 2 recent studies have not shown any increased incidence of tumor dissemination following simultaneous endoscopic biopsy and ETV in patients harboring posterior third ventricular tumors.[9,23]

## Conclusions

Endoscopic tumor biopsy and simultaneous CSF diversion procedures using a rigid lens endoscope with a single bur hole technique are safe and efficacious. In the present study there was an overall success rate of 83% for the biopsies and 86% for the ETVs. A concordance rate of 75% was found in patients who underwent an initial biopsy and a subsequent microsurgical approach for tumor excision. Biopsies from the pineal region had a high success rate of 83%, whereas there was a relatively poor diagnostic yield from biopsies from a small number of superior vermian lesions. We believe that a single bur hole technique using a rigid lens scope is adequate in most circumstances and should be supplemented by a thinner rigid fiberscope in indicated patients.

### Disclosure

The authors report no conflicts of interest concerning the materials or methods used in this study or the findings specified in the paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Mohanty, Satish. Acquisition of data: all authors. Analysis and interpretation of data: Mohanty, Santosh, Biswas. Drafting the article: all authors. Critically revising the article: Mohanty, Santosh, Devi, Satish. Reviewed final version of the manuscript and approved it for submission: Mohanty, Santosh.

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# Idiopathic bilateral stenosis of the foramina of Monro treated using endoscopic foraminoplasty and septostomy

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Hydrocephalus caused by stenosis of the foramen of Monro is rare. The authors describe a 28-year-old female patient with bilateral foraminal stenosis treated using endoscopic septostomy and unilateral foraminal balloon plasty (foraminoplasty). The patient's hydrocephalus and symptoms resolved postoperatively. Endoscopic strategies may be employed as first-line therapy in this condition. *(DOI: 10.3171/2011.1.FOCUS10298)*

**Key Words** • **atresia** • **foramen of Monro** • **foraminoplasty** • **hydrocephalus** • **stenosis** • **diagnostic and operative techniques**

Hydrocephalus secondary to stenosis of the foramen of Monro is rare.[18] Foraminal stenosis has been attributed to infectious origins (particularly TORCH infections) causing inflammation and subsequent scarring in the region,[2,3] congenital atresia,[7,9,19,22,24] vascular malformations,[23] and neoplastic processes,[7] particularly thalamic or intraventricular tumors. Unilateral hydrocephalus from foraminal stenosis may be treated using shunting[7] or endoscopic procedures.[14] We report a case of idiopathic bilateral stenosis of the foramina of Monro causing obstructive hydrocephalus and describe an endoscopic technique used to treat this rare condition.

## Case Report

*History and Presentation.* This patient was a 28-year-old woman with a 3-year history of headaches who presented with episodic near syncope and progressive lethargy. She had no history of meningitis or other inflammatory conditions. There were no focal neurological deficits on examination. The patient was normocephalic. Her fundoscopic examination was notable for papilledema. An MR image revealed enlargement of both lateral ventricles and a very small third and fourth ventricle consistent with stenosis of both foramina of Monro and patency of the cerebral aqueduct and fourth ventricular outlet (Fig. 1A and B). The patient began to receive acetazolamide, which provided some headache relief, but her symptoms returned shortly. She was referred to our center for further evaluation and treatment. After discussing the risks and benefits of various treatment options with the patient, including shunt placement and continued medical management, we recommended a Monro foraminoplasty and septostomy.

*Abbreviation used in this paper:* TORCH = toxoplasmosis/toxoplasma gondii, other infections, rubella, cytomegalovirus, and herpes simplex virus.

*Operation.* The patient was positioned supine on the operating table and placed in a Mayfield head holder. Using frameless stereotactic guidance, an incision and bur hole were made on the left coronal suture approximately 2 cm off midline, and a trajectory was planned toward the ipsilateral foramen of Monro. The left side was used in this instance because the right ventricle was slightly larger than the left, enabling a safer penetration into the contralateral frontal horn during septostomy.

After the dura was coagulated and incised, a 0° Aesculap MINOP endoscope with a Xenon light source was passed through a 14 Fr introducer sheath into the left frontal horn (Video 1).

**Video 1.** Clip showing the Monro foraminoplasty. Click here to view with Windows Media Player. Click here to view with Quicktime.

We confirmed our location by identifying the septum on the right side of our field. We visualized the left foramen on Monro, which was occluded by a thin, translucent membrane (Fig. 2). The choroid plexus appeared normal and there was no evidence of tumor.

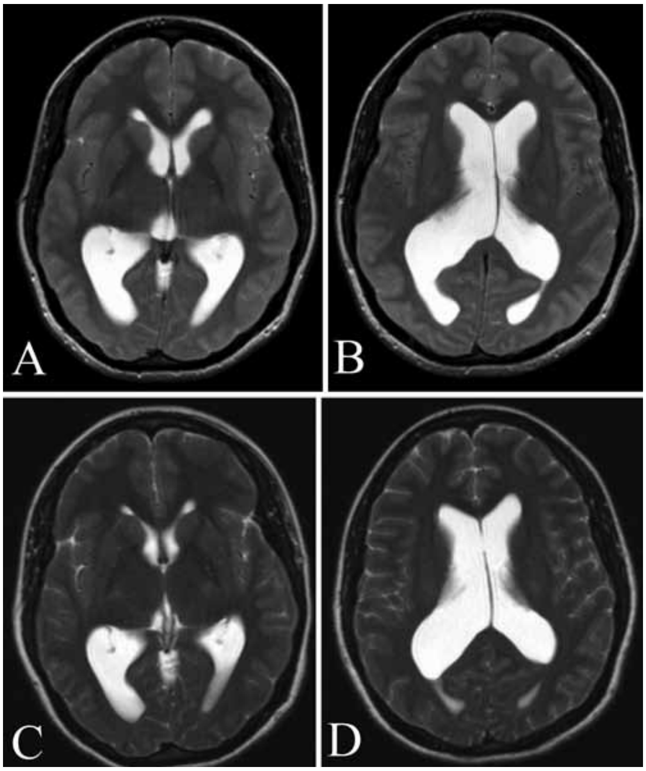


**Fig. 1.** Preoperative axial T2-weighted MR imaging sequences **(A and B)** show enlargement of bilateral lateral ventricles accompanied by small third and fourth ventricles suggesting stenosis at the level of both foramina of Monro. Postoperative axial MR imaging **(C and D)** shows smaller ventricular caliber and redistribution of CSF along the cortical subarachnoid spaces.

Using bipolar and monopolar electrocautery, we made a large fenestration in the septum pellucidum and entered the right frontal horn through this septostomy (Fig. 3). We inspected the right foramen of Monro and found that it was not patent.

We removed the endoscope and switched to a 30° angled scope. We maneuvered into the left frontal horn again, tracing the choroid plexus to the occluded left foramen of Monro. The 5 Fr Fogarty catheter was advanced into this foramen and balloon-dilated the opening (Fig. 4). After the foramenoplasty, the orifice was patent, the third ventricle was visualized, and a brisk flow of CSF was noted. The endoscope was slowly removed and no bleeding was noted. A third ventriculostomy was not performed, as the cerebral aqueduct and fourth ventricular outflow were patent.

*Postoperative Course*. The patient was observed in the neurosurgical intensive care unit overnight and discharged on postoperative Day 2 without any complications. At the 1-month follow-up visit, the patient's headaches and papilledema had resolved. She underwent MR imaging (Fig. 1C and D), which showed smaller ventricular caliber and expansion of the cortical subarachnoid spaces. She reported no headaches 1 year after surgery.

## Discussion

Stenosis of the foramen of Monro, either unilateral or

**Fig. 2.** Intraoperative endoscopic photo showing the thalamostriate and septal veins merging posterior to the left foramen of Monro, which is occluded by a thin, translucent membrane. The choroid plexus appears normal and there is no evidence of tumor.

bilateral, is a rare occurrence.[2,10,22] Infectious, neoplastic, vascular, and developmental causes have been implicated in this type of stenosis.[2–4,6,7,9,10,12,17–19,22–24] Our patient had no history of an infectious condition, and there was no evidence of a neoplastic or vascular process on MR imaging or intraoperatively.

Endoscopic techniques have proven safe and effective in treating hydrocephalus caused by foraminal stenosis,[14] and spare the patient the high lifelong cumulative risk of shunt failure.[20] Fenestration of the foramen of Monro[13] or septum pellucidum[5] have been used for unilateral foraminal stenosis. In a series of 32 patients who underwent septostomy for isolated lateral ventricular hydrocephalus, the initial success rate was 53%, which increased to 81% with repeat procedures.[1] Procedural risks include the inability to fenestrate the septum and intraventricular hemorrhage; these risks appear to be increased in the presence of distorted anatomy or a thickened septum.[1] Compared with septostomy, there are no large series describing outcomes of foraminoplasty. However, 10 of 13 patients combined from recent series had acceptable outcome without the

**Fig. 3.** Intraoperative endoscopic photos showing a septostomy performed **(left)** and a large defect in the septum pellucidum that now allows communication between the left and right lateral ventricles **(right)**.

**Fig. 4.** Intraoperative endoscopic photos showing the Fogarty catheter inserted into the left foramen of Monro **(left),** which was inflated to disrupt the membranous occlusion of this orifice and restore CSF flow into the third ventricle **(right)**.

need for a shunt after the procedure (Table 1).[8,11,13,15,16,21,25] Foraminoplasty may be performed safely in the presence of a thin avascular membrane covering the foramen.[13] However, if the foramen is atretic or obscured, there is increased risk of injury to the fornix. In this instance, shunting[6] or septostomy[13] may be performed.

By performing a septostomy and unilateral foraminoplasty, we were able to restore CSF flow in a patient with bilateral obstructions at the foramina of Monro. We did not believe an endoscopic third ventriculostomy was indicated because the third ventricle was small and there was no evidence of outflow obstruction. Postoperatively, the patient's symptoms resolved, her fundoscopic examination results returned to normal, and her MR imaging results showed improvement in ventricular size with redistribution of the CSF along the cortical subarachnoid spaces. Potential complications of this endoscopic approach include injury to the nearby fornix, deep veins, or internal capsule, but are rare in our experience. In the presence of favorable anatomy, hydrocephalus caused by bilateral stenosis of the foramina of Monro may be effectively treated with endoscopic septostomy and unilateral foraminoplasty.

**Disclosure**

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: all authors. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: all authors. Reviewed final version of the manuscript and approved it for submission: all authors. Administrative/technical/material support: all authors. Study supervision: Harter.

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**TABLE 1: Studies reporting the outcome of endoscopic fenestration of the foramen of Monro***

| Authors & Year | Age | Postop Ventricular Size | Follow-Up Period (no shunt required) | Postfenestration Day (shunt required) |
|---|---|---|---|---|
| Mohanty et al., 1996 | NR | NR | NR | |
| Oi et al., 1999 | 7 yrs | unchanged | 5 yrs | |
| Kumar, 1999 | NR | NR | NR | |
| | NR | NR | | NR |
| Wong & Lee, 2000 | 2 yrs | NR | | 5 |
| | 9 yrs | NR | 14 mos | |
| Freudenstein et al., 2002 | 37 yrs | unchanged | | 3 |
| | 62 yrs | decreased | 1 yr | |
| Spennato et al., 2007 | 2 yrs | NR | 27 mos | |
| | 5 yrs | NR | 12 mos | |
| | 8 yrs | NR | 26 mos | |
| Oi & Enchev, 2008 | 10 days | decreased | 1 yr | |
| | 11 days | decreased | 5 yrs | |

* NR = not reported.

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*Supplemental online information:*

Video: http://mfile.akamai.com/21490/wmv/digitalwbc.download.akamai.com/21492/wm.digitalsource-na-regional/focus10-298.asx (Media Player).

http://mfile.akamai.com/21488/mov/digitalwbc.download.akamai.com/21492/qt.digitalsource-global/focus10-298.mov (Quicktime).

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# Emerging technology in intracranial neuroendoscopy: application of the NICO Myriad

## Technical note

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Improvement in fiber optics and imaging paved the way for tremendous advancements in neuroendoscopy. These advancements have led to increasingly widespread use of the endoscope in neurosurgical procedures, which in turn incited a technological revolution leading to new approaches, instruments, techniques, and a diverse armamentarium for the treatment of a variety of neurosurgical disorders. Soft-tissue removal is often a rate-limiting aspect to endoscopic procedures, especially when the soft tissue is dense or fibrous. The authors review a series of cases involving patients treated between August 2009 and October 2010 with a new device (the NICO Myriad), a non–heat-generating, oscillating, cutting, and tissue removal instrument that can be used through the working channel of the endoscope as well as in open neurosurgical procedures. They used this device in 14 purely endoscopic intracranial procedures and 1 endoscope-assisted keyhole craniotomy. They report that the device was easy to use and found that tissue resection was more efficient than with other available endoscopic instruments, especially in the resection of fibrotic tissue. There were no observed device-related complications. The authors discuss the technical aspects of using this device in endoscopic resection of pituitary tumors, craniopharyngiomas, and colloid cysts. They also demonstrate its use in hydrocephalus and intraventricular clot removal and discuss its potential use in other neurosurgical disorders. *(DOI: 10.3171/2011.2.FOCUS10312)*

**Key Words** • **hydrocephalus** • **pituitary tumor** • **colloid cyst** • **craniopharyngioma** • **intraventricular clot** • **surgical technique**

Since the beginning of modern medicine, neurosurgeons have tried to find more efficacious and efficient ways to surgically treat intracranial tumors, hydrocephalus, seizures, and many other neurological disorders. Utilizing an endoscope for visual assessment of the ventricular system as well as other parts of the brain is a very old concept. With a unique combination of technological advancements in lens development,[2] charge-coupled devices, and fiber optics, this old concept became a widespread reality in the last 2 decades.[31] The endoscope is now an essential tool of the neurosurgeon and is used alone or in an accessory fashion during microsurgery for the treatment of many different types of intracranial and spinal pathology.

As with all technology, there are limitations in neuroendoscopy that need to be overcome. Depending on the size of a lesion, a purely endoscopic approach for resection may be technically difficult or require significant operative time, given the difficulties with efficient debulking of masses larger than a few centimeters in diameter due to a lack of endoscopic instrumentation. This may lead to abandoning the consideration of an endoscopic approach in favor of a more traditional open procedure. There is a need for technology that works in conjunction with the endoscope for more efficient removal of soft tissue and lesions that otherwise would be more difficult to remove with simple suction and current endoscopic tumor forceps and dissectors.

The NICO Myriad (NICO Corp.) is a recently developed device that is used in multiple intracranial endoscopic procedures for soft-tissue resection. We report on a series of cases in which we utilized this tool in the resection of pituitary adenomas, craniopharyngiomas, and colloid cysts. We also demonstrate its use in hydrocephalus and intraventricular clot removal, and discuss its potential use in other neurosurgical disorders. We discuss the advantages and disadvantages of using this device in these illustrated cases.

## Patient Population and Surgical Device

*Patient Population*

Between August 2009 and October 2010, 14 patients underwent purely endoscopic intracranial procedures and 1 patient underwent an endoscope-assisted open keyhole craniotomy at the University of Iowa Hospitals and Clinics in which the NICO Myriad was used for various reasons (Table 1). Of these 15 patients, 5 patients had pituitary adenomas, 3 had colloid cysts, 3 had craniopharyngiomas, 2 had loculated hydrocephalus, 1 had a pineoblastoma, and 1 had a tuberculum sellae meningioma.

*Surgical System*

The NICO Myriad is a minimally invasive surgical system specifically designed for the removal of intracranial and skull-base soft tissues with direct, microscopic, or endoscopic visualization (Fig. 1A–E). The technology platform is based on combining a high-speed reciprocating inner cannula within a stationary outer cannula and electronically controlled variable suction. The instrument relies on a side-mouth cutting and aspiration aperture located 0.6 mm from the blunt dissector end (Fig. 1E). The functions of the device are operated via a foot pedal that allows for precise control of the variable-strength suction and activation or deactivation of the cutting blade (Fig. 1A). The combination of gentle forward pressure of the aperture into the tissue to be removed and suction draws the desired tissue into the side aperture, allowing for controlled and precise tissue resection through the reciprocating cutting action of the inner cannula. In addition to the suction strength being controlled by the graded amount of depression of the foot pedal, the strength can be governed via a knob on the console (Fig. 1A and B). Importantly, the surgeon can immediately stop suction by lifting his foot off the foot pedal (Fig. 1A). This allows the surgeon to observe precisely the tissue that is to be cut and resected and avoid cutting structures drawn into the aperture inadvertently. The aperture can be rotated via a control knob on the handpiece, and the shaft can be gently bent if needed (Fig. 1C). All removed tissue can be captured in the collection chamber (Fig. 1B), which allows for pathological analysis with limited crush artifact from the device.

Unlike ultrasonic devices[3] or laser devices,[19] the Myriad is purely mechanical and generates no heat at the resection site or along its shaft (Fig. 1C and E). It may also be used for spinal tissue or tumor resection in minimally invasive and open surgical approaches. It is a multifunctional instrument that combines the capabilities of scissors, suction, and a blunt dissector (Fig. 1E). The device's low-profile design provides improved access to hard-to-reach tumor sites and better visibility to the surgical field, especially during tumor resection through narrow corridors (Fig. 1B–E). The system is available in a variety of diameters, lengths, and configurations to meet the diverse needs of patients and clinical presentations in intracranial, skull base, and endoscopic procedures. The reusable main console, stand, and foot pedal (Fig. 1A and B) cost approximately $94,000 (US) and the single-use disposable handpieces (Fig. 1C) cost around $2900.

## Results and Illustrative Cases

In all cases, the device was easy to use and we found tissue resection to be safe and efficient. There were no observed device-related complications.

*Tumor Resection*

Neuroendoscopic techniques and approaches are of-

**TABLE 1: Summary of clinical and demographic characteristics in patients treated using the Myriad system***

| Case No. | Age (yrs), Sex | Diagnosis | Approach | Reason for Use |
|---|---|---|---|---|
| 1 | 46, M | fibrous pituitary adenoma | transsphenoidal | tumor resection |
| 2 | 31, F | colloid cyst | transcortical | tumor resection, septostomy, intraventricular clot removal |
| 3 | 74, F | fibrous pituitary adenoma | transsphenoidal | tumor resection |
| 4 | 7, M | loculated hydrocephalus | transcortical | cyst fenestration |
| 5 | 49, F | craniopharyngioma | transsphenoidal | tumor resection |
| 6 | 31, F | colloid cyst | transcortical | tumor resection |
| 7 | 27, M | prolactinoma | transsphenoidal | tumor resection |
| 8 | 52, F | craniopharyngioma | transsphenoidal | tumor resection |
| 9 | 67, F | craniopharyngioma | transsphenoidal | tumor resection |
| 10 | 32, F | loculated hydrocephalus | transcortical | cyst fenestration |
| 11 | 47, F | tuberculum sella meningioma | subfrontal craniotomy | tumor resection |
| 12 | 26, F | colloid cyst | transcortical | tumor resection |
| 13 | 58, M | prolactinoma | transsphenoidal | tumor resection |
| 14 | 25, F | pineoblastoma | transcortical | tumor resection |
| 15 | 77, F | pituitary adenoma | transsphenoidal | tumor resection |

* There were no device-related complications.

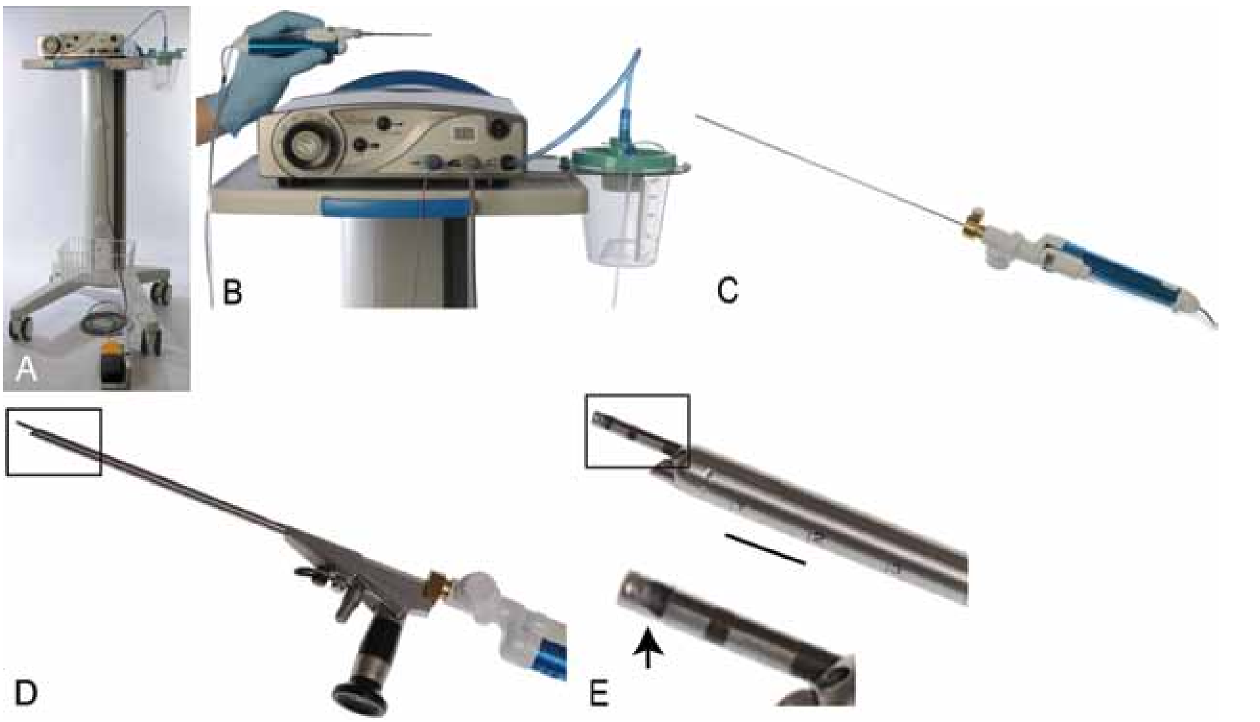


**Fig. 1.** The Myriad system. **A:** The entire system, with console, collection chamber, and foot pedal on movable stand. **B:** Close-up view of the console, handpiece, and collection chamber. **C:** Close-up view of the handpiece resection instrument. **D:** The NICO Myriad 1525 intraventricular resection device inserted into an Aesculap MINOP WC endoscope. **E:** Close-up view of the end of the resection device in the endoscope from panel **D**; *arrow* points to the side-mouth cutting and aspiration aperture, which is located 0.6 mm from the blunt dissector end to protect neurovascular and other critical structures. Bar = 1 cm.

ten considered too difficult for treatment of large intracranial tumors due to prolonged operative time and lack of instrumentation for efficient cytoreduction with acceptable preservation of normal surrounding structures. This limitation spurred the creation of the NICO Myriad, which is designed for working within the limited space provided by the endoscope for efficiently removing intracranial tumors without generating heat or damaging adjacent eloquent brain tissue.

*Pituitary Adenoma*. In the last 2 decades, the endoscopic endonasal transsphenoidal approach[22] has become a very common procedure for resection of parasellar masses.[1] To make this approach more feasible, microneurosurgical instruments were modified.[4,21] However, technological limitations still persist. Pituitary macroadenomas are usually soft and friable but have been reported to be fibrous and tough in 5%–13.5% of cases.[17] Fibrous macroadenomas can be difficult to remove with simple suction and ring curettes.[35] We demonstrate an illustrative case in which the Myriad helped remove a fibrous pituitary macroadenoma (Case 7 in Table 1). This 27-year-old man with a history of headaches was found on MR imaging to have a large sellar prolactinoma (Fig. 2A), which became unresponsive to medical therapy and required surgical intervention. The patient underwent endoscopic endonasal transsphenoidal resection of the mass. He had been previously treated with cabergoline, and the pituitary tumor was quite fibrous[28] (Fig. 2C–G). Using standard suction and ring curettes proved to be difficult and time consuming; therefore the Myriad was used for resection (Fig. 2C–G). After centrally debulking the tumor, we were able to quickly shave the tumor off the diaphragma sellae (Fig. 2C–E) without tearing the diaphragma (Fig. 2F and G). In endonasal approaches such as this, the Myriad can be used directly, adjacent to a standard 4-mm endoscope, and without a working channel. It is also compatible with microsurgical endonasal approaches. Gentle bending of the tip can provide additional working angles and trajectories when used with angled endoscopic views. Rotation of the tip via the handpiece dial facilitates direction of the cutting aperture away from critical structures such as the cavernous sinus or internal carotid arteries. Our patient experienced no complications and did well postoperatively; near-total resection of the macroadenoma was achieved, despite the fibrous nature of the tumor (Fig. 2B).

*Craniopharyngioma*. Craniopharygiomas are challenging to resect through an open[12,13] or transsphenoidal approach.[7,9,20,29] Many surgeons have demonstrated successful resection of craniopharyngiomas through an extended endoscopic endonasal transsphenoidal approach.[7,14,20] Nevertheless, endoscopic resection of thickened cyst walls and nonfriable tumor tissue can be difficult. We present an illustrative case (Case 5) of a 49-year-old woman who presented with headaches and hormonal imbalance, with MR imaging demonstrating an enlarging sellar and suprasellar cystic and solid mass with extension into the interpeduncular cistern and mass effect on the midbrain (Fig. 3A). She underwent an extended endoscopic endonasal transsphenoidal resection of the tu-

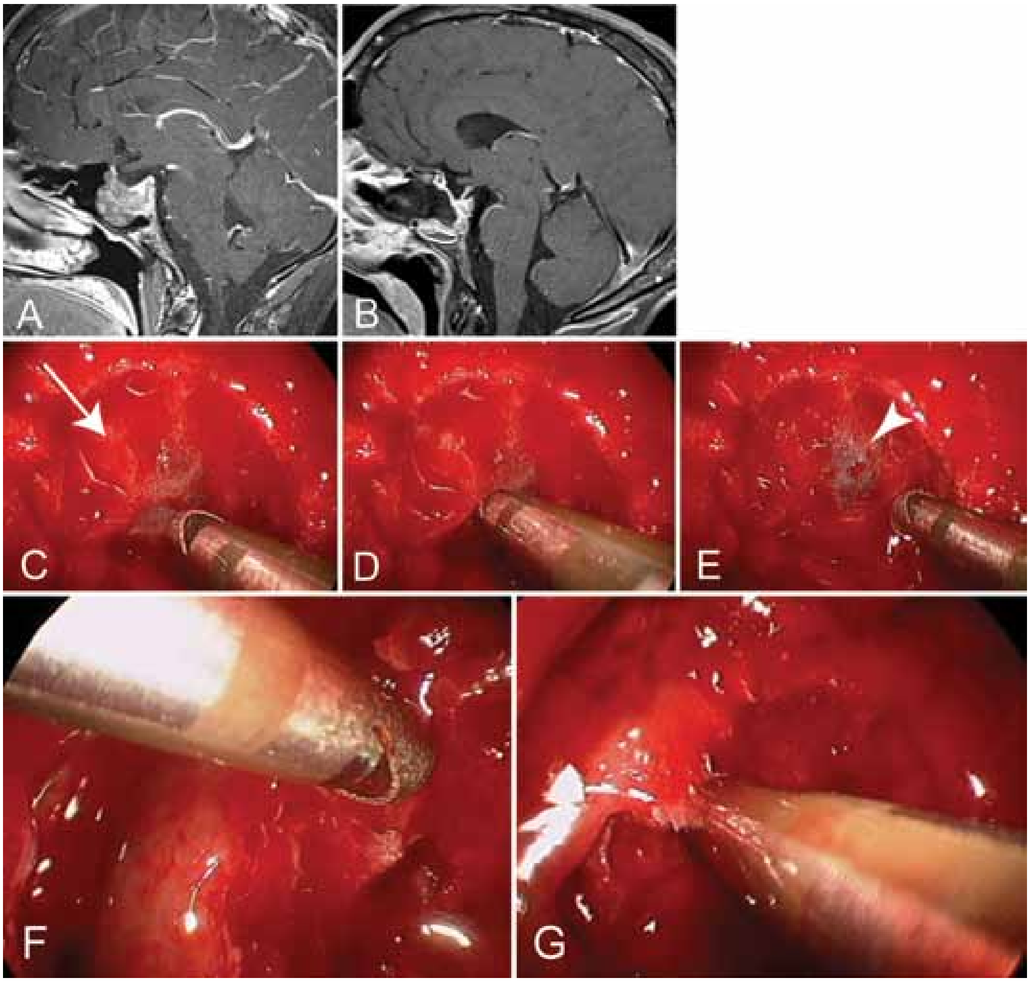

**Fig. 2.** Case 7. Fibrous pituitary macroadenoma. **A:** Preoperative sagittal contrast-enhanced T1-weighted MR image demonstrating a large mass expanding the sella. **B:** Postoperative contrast-enhanced T1-weighted MR image obtained after a NICO Myriad–assisted endoscopic approach demonstrating near-total resection of the macroadenoma. **C–E:** Intraoperative images showing (in time-lapse fashion) the use of the device to remove tumor *(arrow)* off the right lateral aspect of the diaphragma sellae *(arrowhead)*. **F and G:** Removal of the right lateral sellar tumor component demonstrating the varied trajectory and angles achieved with the device.

mor (Fig. 3C–F). The solid component and cystic walls required extensive dissection. The Myriad allowed us to quickly debulk the tumor and facilitated capsular dissection. There were no complications, and a complete resection of the craniopharyngioma was achieved (Fig. 3B).

*Colloid Cyst*. Colloid cysts can be resected through an open or an endoscopic procedure. Many find a purely endoscopic approach to be effective in resection, such that it is often the procedure of choice.[15] Nevertheless, colloid cysts vary in size and consistency, and the cyst contents and walls are often thick and can be difficult to resect using a working-channel endoscope. We have used the Myriad in purely endoscopic resection of colloid cysts. After initial puncture and opening of the cyst, we were able to efficiently remove the often thick or semisolid cyst contents with the suction and cutting aspects of the device. After central debulking, one can then quickly remove large parts of the cyst wall to facilitate complete excision. This technique can prevent damage to the fornix, as large parts of the lesion are not drawn through the foramen of Monro, and the handpiece aperture can be directed away from the fornix or adjacent veins while in use. Here we present a case of a 31-year-old woman who presented with a 1-week history of nausea and vomiting and was found to have papilledema on physical examination (Case 6). An MR imaging study demonstrated a large mass in the superior aspect of the third ventricle (Fig. 4A). We approached the mass with the endoscope from a left frontal bur hole and initially punctured the cyst (Fig. 4C and D), which allowed us to completely remove the cyst contents with the Myriad (Fig. 4H and I). The suction and cutting aspect of the device allowed us to quickly resect parts of the cyst wall (Fig. 4E–G), and we achieved a complete resection of the colloid cyst (Fig. 4B and J).

### *Hydrocephalus*

The endoscope is used in many cases of obstructive hydrocephalus because a third ventriculostomy can be effective in 70%–80% of these cases.[34,42] However, cases of loculated hydrocephalus are more complex and challeng-

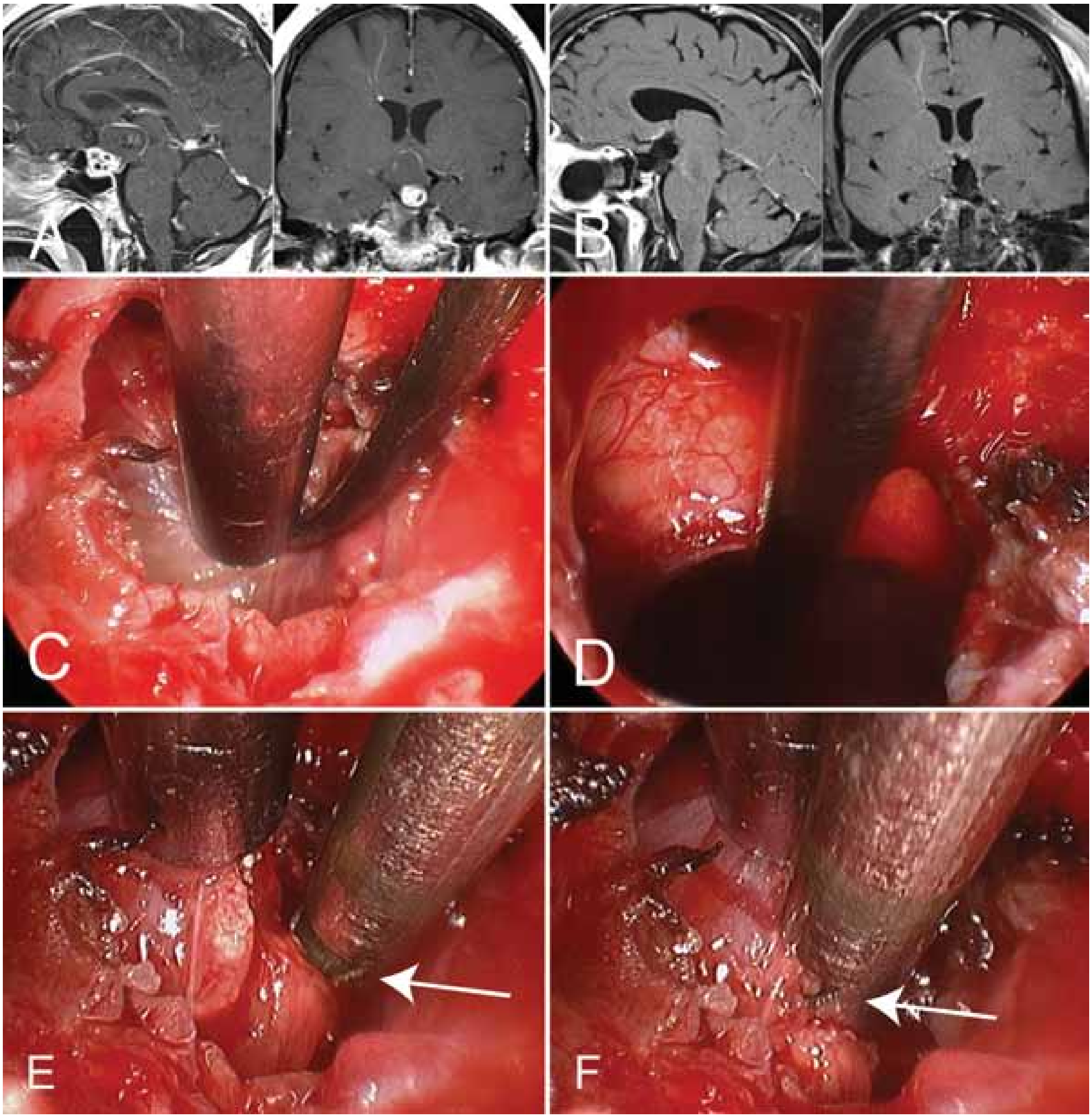


**Fig. 3.** Case 5. Craniopharyngioma. **A:** Preoperative sagittal and coronal contrast-enhanced T1-weighted MR images demonstrating a large enhancing sellar and suprasellar cystic and solid mass with extension into the interpeduncular cistern and mass effect on the midbrain. **B:** Postoperative sagittal and coronal contrast-enhanced T1-weighted MR images obtained after a purely endoscopic approach, showing complete resection of the craniopharyngioma. **C–F:** Intraoperative images. A large cystic and solid mass was noted upon opening the sella **(C)**. Myriad-assisted endoscopic resection in and around the optic chiasm **(D)** provided a complete resection. The Myriad device is shown in open (*arrow* in **E**) and cutting modes (*arrow* in **F**) removing pieces of the craniopharyngioma.

ing.[11] Enlarging loculated components of the ventricular system along with trapped ventricles require fenestration to establish communication between these areas and other compartments within the ventricular system that are able to absorb CSF, or to use a single ventriculoperitoneal shunt catheter.[11,39] These loculated walls are often thick due to previous infection or hemorrhage (Fig. 5A), and creating an adequate fenestration can require a significant amount of time. The Myriad can be used to quickly and cleanly enlarge a fenestration (Fig. 5B). Unlike the usual blunt fenestration techniques, the device's cutting action produces a smooth edge to the walls of the created fenestration (Fig. 5C). This is illustrated in the case of a 32-year-old woman who presented with bilateral shunt infection/malfunction and a history of loculated hydrocephalus and a supratentorial primitive neuroectodermal tumor in childhood (Case 10). After removal of the shunt systems and antibiotic treatment, we used the endoscope to explore the extensive adhesions within the right and left ventricular systems. The Myriad enabled us to efficiently create a communication between the ventricular systems with large smooth-edged fenestrations, allowing us to place a unilateral ventriculoatrial shunt instead of the previous bilateral system. Additional case studies with longer-term follow-up are needed

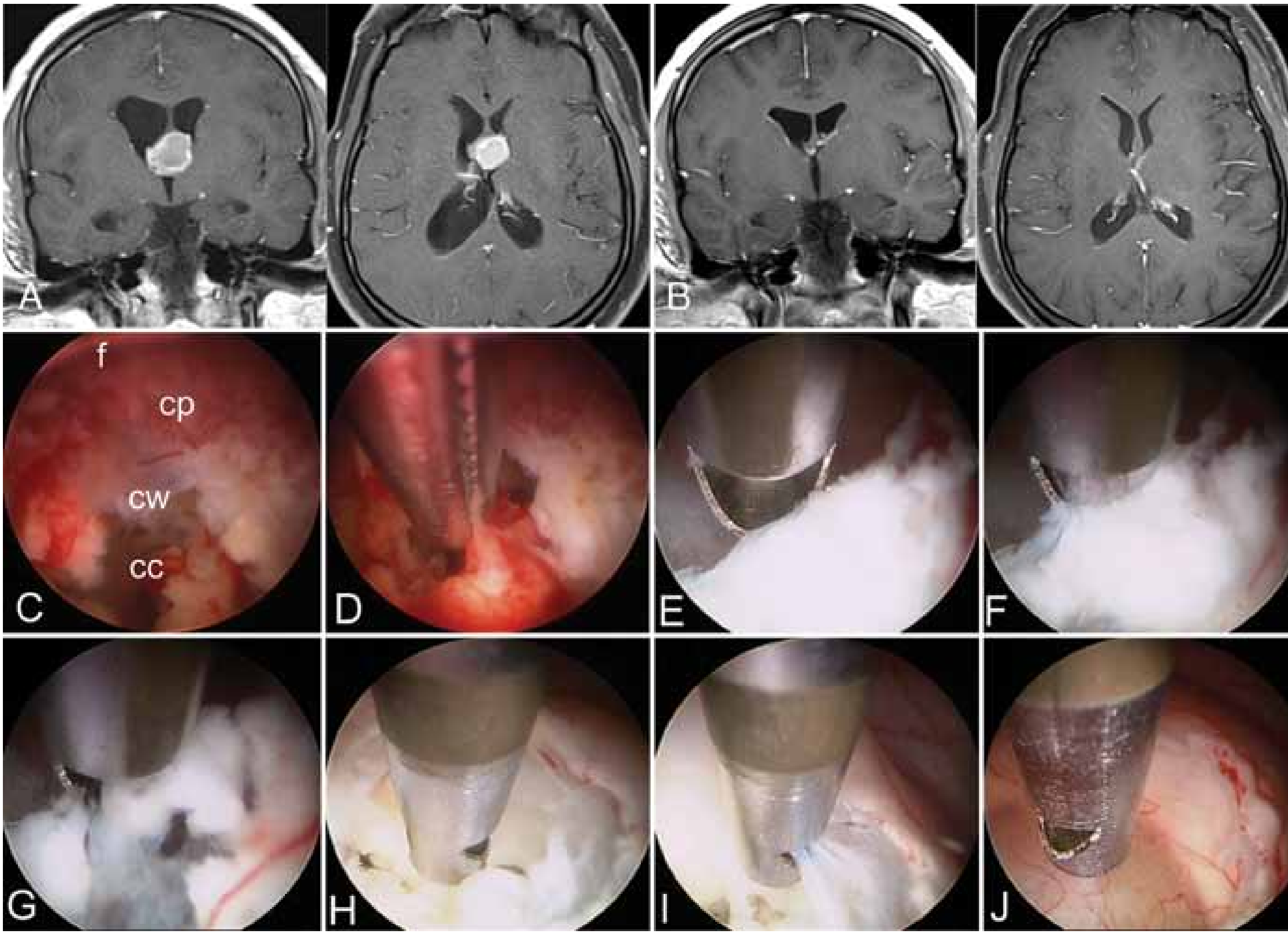


**Fig. 4.** Case 6. Colloid cyst. **A:** Preoperative coronal and axial contrast-enhanced T1-weighted MR images demonstrating a large enhancing mass in the superior aspect of the third ventricle bulging into the left Monro foramen and left lateral ventricle. **B:** Postoperative contrast-enhanced T1-weighted MR images obtained after a purely endoscopic approach demonstrating complete resection of the colloid cyst. **C:** View through the endoscope of the colloid cyst after initial puncture, showing the fornix (f), choroid plexus (cp), cyst wall (cw), and cyst contents (cc). **D:** Forceps closing on a piece of the cyst wall demonstrating its thick and fibrotic nature. **E–G:** A time-lapse sequence of intraoperative images demonstrating the precise suction and cutting action of the Myriad. The device is open in **(E)** and suctioning and cutting a small piece of the cyst wall **(F)** for removal **(G)**. **H and I:** Intraoperative images showing suction and removal of the cyst contents. **J:** Complete resection of the colloid cyst.

to determine if such techniques lead to lower reloculation or cyst recurrence rates.

*Intraventricular Hematoma*

Neuroendoscopic evacuation of intraventricular hematomas has been found to shorten the duration of external ventricular drainage.[26,36] The intraventricular hematoma is often quite thick, making evacuation with suction difficult. The Myriad is able to suction and shave pieces of the clot, enabling a faster removal of the hematoma from within the ventricular system. This is demonstrated in the case of a 31-year-old woman who underwent a purely endoscopic resection of a colloid cyst (Case 2). After the Myriad-assisted complete resection of the cyst, an acute clot formed. We used the Myriad to resect the clot in the lateral and third ventricles (Fig. 6A and B) and create a septostomy. Both foramina of Monro were inspected and found to be patent.

## Discussion

The technological advancements made inside the field of neurosurgery are due in large part to advancements made outside the field of medicine. The introduction of the surgical microscope[27,40] and use of smaller dissecting instruments[41] specifically designed for manipulating tissue around delicate and eloquent brain structures helped make possible what we now know as modern microneurosurgery.[40] For example, laser technology[32] was first introduced to the field of neurosurgery in the 1960s for treatment of intracerebral neoplasms. This technology has evolved into use as a laser scalpel for fenestration of arachnoid cysts, cerebrovascular bypass, and dural reconstruction along with treatment of intracerebral and intraspinal tumors.[19] The use of the ultrasonic aspirator in neurosurgery was first reported in 1978 for the removal of intraaxial and extraaxial tumors and is now a mainstay in intracranial tumor resection.[3,18] Just as the previous technologies relied

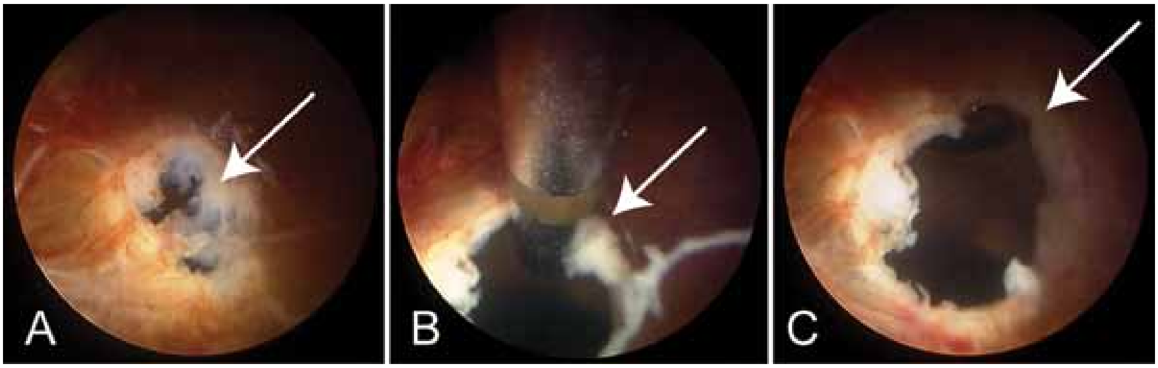


**Fig. 5.** Case 10. Loculated hydrocephalus. **A:** An initial puncture to a ventricular wall created a small fenestration *(arrow)*, which required enlargement with a dilating device. **B:** We were quickly able to remove the frayed pieces *(arrow)* of the punctured ventricular wall with the Myriad. **C:** The suction and sharp cutting aspects of the device allows the fenestration to be quickly and cleanly enlarged, creating a smooth communication *(arrow)* and preventing possible future scar formation.

on advancements outside of medicine, better imaging,[2,33] fiber optics, and lens development led to the emergence and widespread use of the endoscope in neurosurgical procedures.[31,43]

Applications of intracranial neuroendoscopy continue to expand as technology improves.[5,6] Colloid cysts are becoming more commonly treated through purely endoscopic techniques.[15] The anterior skull base is becoming more commonly approached inferiorly through an endoscopic endonasal approach.[8,10,23,24] The extended transsphenoidal approach is gaining popularity for large pituitary adenomas[10] and craniopharyngiomas[8] invading the suprasellar space. Improved techniques for reconstructing the skull base[16,25,37] after an endoscopic procedure are making these endonasal procedures more frequent. This has sparked both the need for and the creation of devices for tumor and tissue resection using these minimally invasive approaches.

The working channel of the rod-lens endoscope provides a single avenue for a variety of tools in neuroendoscopic procedures. Instruments, each serving a specific purpose, have been invented to grab, suction, coagulate, cut, or dissect tissue. We report on a device that combines many of those functions into one handpiece that works through the working channel of two commonly used rigid neuroendoscopic systems (Aesculap Co. and Karl Storz GmbH & Co.). The Myriad is a novel device that appears to be of most benefit in resection of thicker tissue that otherwise would be time consuming or impossible to remove with simple suction and dissectors. Its other additional benefits rely on its multifunctional capacity making neuroendoscopic procedures more efficient by combining actions of multiple single-function instruments.

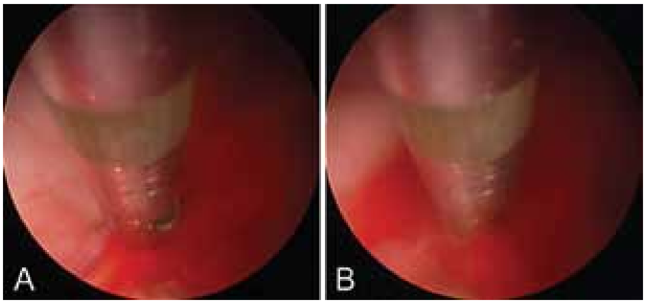


**Fig. 6.** Case 2. Intraventricular hematoma. **A:** After a purely endoscopic resection of a colloid cyst, an acute clot formed and the Myriad was used for clot evacuation. **B:** With precise control of suction and the oscillatory cutting action of the device, we were able to quickly suction and remove pieces of the hematoma until it was entirely evacuated.

Although the Myriad is the first mechanical device invented for use through the working channel, other instruments have been designed for tissue removal through the working channel, including an ultrasonic aspirator,[38] developed and designed specifically for the universal GAAB neuroendoscopic system (Karl Storz GmbH & Co.). Oertel et al.[38] used this device in 2 patients with pituitary adenomas, 2 patients with obstructive hydrocephalus from intraventricular clot blocking the aqueduct, and 1 patient with obstructive hydrocephalus caused by blocking of the aqueduct by a cystic craniopharyngioma. It was effective in all patients without complications. Another instrument used for tissue removal includes a variable-aspiration tissue resection device, which was used in 2 patients with third ventricular hamartomas.[30]

### *Other Potential Uses of the Myriad System*

As endoscopic techniques become more widespread, the trend of minimalism in neurosurgery for less brain retraction and therefore less damage to eloquent brain structures will lead to an even greater use of the endoscope in intracranial lesion resection. The ability to precisely and efficiently remove these lesions depends on the technology developed. Intraventricular tumors and cysts are ideal lesions for the application of neuroendoscopy and resection with assistance of the Myriad system. Other intracranial tumors such as acoustic neuromas may benefit from its precise control. Similar to loculated hydrocephalus, arachnoid cysts throughout the brain or ventricular system are amenable to fenestration enlargement with the Myriad. Elimination of the typically frayed edges of cyst wall fenestrations may prevent future scar development and facilitate a better outcome. It appears that the uses for this device are multiple within intracranial surgery. This capacity for use across disciplines and procedures is important when health care purchasing budgets are limited. As a result, it is likely that the Myriad will become a mainstay and reliable companion in neuroendoscopy.

*Summary of Advantages and Disadvantages*

In the 15 cases in which we used the Myriad system (Table 1), we experienced or observed the following advantages: precise resection control (controlled tissue resection with the ability to observe tissue prior to cutting and removal through variable-strength suction); the combination of multiple tools in one handpiece (scissors, suction, blunt dissection), making tissue resection more efficient than existing endoscopic instrumentation; rapid control of suction strength with capability of immediate cessation of suction, which enhances safety during intraventricular procedures and around critical structures; notably improved resection speed compared with other purely endoscopic instruments; lack of heat generation; low-profile handpiece, which aids visualization (Fig. 1D); compatibility with working-channel endoscopes (Fig. 1D); collection of aspirated tissue (Fig. 1B) with minimal crush artifact (an advantage for tumor tissue analysis); malleability of tip (up to 30°); and compatibility with both open and endoscopic intracranial procedures.

Disadvantages of the Myriad include the presence of an additional console and equipment in the operating room, the learning curve associated with the device (as with any new device), the lack of hemostatic or cautery capabilities, and the cost associated with the single-use disposable handpiece. In addition, removing extremely fibrous, tenacious tumor tissue is more difficult with the existing Myriad handpiece sizes than with ultrasonic aspirators used in open procedures.

## Conclusions

The Myriad is a minimally invasive surgical system specifically designed for the removal of intracranial and skull-base soft tissues with direct, microscopic, or endoscopic visualization. It is precise in tissue cutting and removal without the use of heat or ultrasonic energy. It is surgeon controlled for real-time variable aspiration for fine-tissue removal. It is effective in efficiently removing fibrous pituitary tumors, craniopharyngiomas, and colloid cysts that otherwise would be technically difficult with standard endoscopic instrumentation, given the consistency of these lesions. It is also effective in enlarging fenestrations for loculated hydrocephalus and removal of intraventricular hematomas. Further uses of this device abound and the Myriad will likely become an important tool in the resection of intraventricular masses.

### Disclosure

None of the authors have any financial relationships with or are employed by the NICO Corporation. Dr. Greenlee is a member of an Aesculap, Inc., advisory board.

Author contributions to the study and manuscript preparation include the following. Conception and design: all authors. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: all authors. Reviewed final version of the manuscript and approved it for submission: all authors. Administrative/technical/material support: all authors. Study supervision: all authors.

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# Arachnoscopy: a special application of spinal intradural endoscopy

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*Object.* The microsurgical removal of obstructions to CSF flow is the treatment of choice in the surgical management of intradural arachnoid cysts. Cardiac-gated phase-contrast MR imaging is an effective tool for the primary diagnosis and localization of arachnoid cysts. Microsurgery, however, does not lend itself to assessments of further adhesions beyond the borders of the exposed area. The use of a thin endoscope allows surgeons to assess intraoperatively whether the exposure is wide enough.

*Methods.* Between 2006 and 2010, a single neurosurgeon performed 31 consecutive microsurgical procedures with endoscopic assistance in 28 patients with spinal arachnoid adhesions. A MurphyScope endoscope was used for this purpose. The CSF flow was studied before and after surgery in all patients by using phase-contrast MR imaging in the region of the craniocervical junction, the cervical spine, the thoracic spine, and the lumbar spine.

*Results.* In all 31 procedures, CSF flow obstructions were detected at the level identified by phase-contrast MR imaging. In 29 procedures, image quality was sufficient for an inspection of the adjacent subarachnoid space. In 6 cases, the surgeon detected further adhesions that obstructed CSF flow in the adjacent subarachnoid space that were not visualized with the microscope. In all cases, these adhesions were identified and removed during microsurgery.

*Conclusions.* Arachnoscopy is a helpful adjunct to microsurgery and can be performed safely and easily. It allows the surgeon to detect further adhesions in the subarachnoid space that would remain undetected by microscopy alone. *(DOI: 10.3171/2011.1.FOCUS10291)*

**Key Words** • **spinal endoscopy** • **arachnoscopy** • **syringomyelia** • **cardiac-gated phase-contrast magnetic resonance imaging** • **arachnoid adhesion** • **cerebrospinal fluid flow** • **cerebrospinal fluid pulsation**

Ventricular endoscopy is an accepted and widely used procedure. Endoscopic third ventriculostomy has become a routine method in almost all neurosurgery departments. By contrast, endoscopy of the spinal subarachnoid space is a method that is not yet routinely used. Arachnoscopy is a procedure that allows surgeons to visualize adhesions that obstruct the subarachnoid space.[5,21]

Spinal intradural arachnoid cysts can lead to neurological symptoms[20] or cause syringomyelia. This is a disorder in which a cavity forms within the spinal cord, and it is associated with a wide variety of diseases. Obstruction of CSF flow either at the craniocervical junction or in the spinal subarachnoid space is a factor common to all conditions that cause syringomyelia.[3] The CSF pulsations are a result of the flow of blood into the nervous system, which leads to a volume shift from cranial to spinal spaces and from the extracellular to the subarachnoid space. Syringomyelia is thus not a disease in itself, but a symptom of a wide variety of diseases that are associated with an obstruction of pulsatile CSF flow.

Spinal intradural CSF flow obstruction can be caused by trauma (for example, accident or previous surgery) or inflammation. In countries with a high incidence of tuberculosis and syphilis such as Ethiopia,[13] severe elongated arachnoid adhesions appear to be more common. In some cases, a true intradural arachnoid cyst is the cause of flow obstruction. The cause underlying the formation of an arachnoid cyst in the apparent absence of inflammation or a similar condition is unknown. Perret et al.[23] postulated that the cysts are caused by a dilation of the septum posticum, which longitudinally divides the posterior subarachnoid space in the midline. This would explain why arachnoid cysts are commonly located dorsal to the spinal cord. More recent publications, however, do not support this theory.[11] Arachnoid webs are a variant of arachnoid cysts.[22] Weblike adhesions do not completely block but considerably obstruct the flow of CSF. Intradural arachnoid cysts can cause neurological symptoms in the absence of syringomyelia simply by compressing the spinal cord.[20,29]

In the past, drains were widely used to treat syringomyelia.[1] This method, however, did not prove effective in the long term.[24] For this reason, most authors today believe that the best treatment for syringomyelia is a causal approach involving the removal of CSF flow obstruction and not the placement of shunts.[2,4,15] Causal treatment requires that the operating surgeon know the exact location of CSF obstruction. In addition, the surgeon must assess intraoperatively whether the exposure is wide enough to allow all adhesions to be removed.

The literature reports that myelography in conjunction with postmyelography CT scanning is the standard method of identifying the location of flow obstruction.[3,16] We were able to show, however, that cardiac-gated phase-contrast MR imaging, which is a completely noninvasive procedure, is more sensitive in detecting adhesions than myelography.[18]

Because the site of flow obstruction can be localized with increasing accuracy, the microsurgical procedure requires only a small opening. In our experience, hemilaminectomy or interlaminar fenestration (that is, unilateral partial removal of adjacent vertebral arches without interruption of continuity) with duraplasty and dural tenting sutures are sufficient in many cases.[19] Larger openings are likely to increase the risk of new scar formation after surgery.[17] Minimizing the size of exposure is, however, associated with growing uncertainty as to whether further relevant adhesions might be found in the vicinity of the exposed area. For this reason, we collected data prospectively and investigated whether the adjunctive use of an endoscope helps the operating surgeon determine the required size of the exposure and thus increases the safety of microsurgical lysis of adhesions.

## Methods

Between 2006 and 2010, a single surgeon in a neurosurgery department performed 31 consecutive microsurgical procedures in 28 patients (13 female and 15 male patients; median age 42 years, range 12–76 years) with intraspinal arachnoid adhesions. After the surgeon completed each procedure, he inspected the subarachnoid space as far as possible in the cranial and caudal directions from the exposed area by using a MurphyScope, which is a single-use disposable endoscope with a diameter of 1.4 mm, 10,000 pixel fibers, a malleable tip, and an irrigation channel. The length of the endoscope can be adjusted as required. The microscope usually allows the surgeon to evaluate 2 vertebral levels. When it is used together with the endoscope, at least 2 further levels—1 in each direction—can be examined additionally. As a result, this technique allows the surgeon to evaluate a total of 4 vertebral levels.

All patients underwent preoperative MR imaging of the brain and the entire spine, including Gd enhancement and cardiac-gated phase-contrast CSF flow studies of the craniocervical junction as well as the cervical, thoracic, and lumbar spine in the median sagittal plane for the visualization of craniocaudal CSF flow. Velocity encoding at 3 cm/second was initially selected, and was increased to 5 cm/second, 8 cm/second, and 10 cm/second if "aliasing" was observed. If no flow was visible at 3 cm/second, we controlled cardiac gating and the position of the field of view, and performed another study at 1 cm/second.

Surgery was performed only on strict indications. When patients presented with syringomyelia as a result of subarachnoid CSF flow obstruction, surgery was performed only in those with evidence of a major increase in syrinx size or with severe syringomyelia and neurological deterioration. Patients who presented with intradural arachnoid cysts and spinal cord compression in the absence of syringomyelia underwent surgery only if spinal cord compression caused clinical signs and symptoms.

Cardiac-gated phase-contrast MR imaging of the entire spine was repeated within the first 7 days of surgery, after 3 months, and after 1 year.

## Results

Six patients had posttraumatic syringomyelia, and 1 female patient had a history of bacterial meningitis. The other 21 adhesions were of unknown origin. Five patients had undergone previous surgery at another institution, 4 of them for syringomyelia and 1 for a traumatic dural tear. One female patient had undergone occipital decompression and duraplasty related to a Chiari malformation. A lumbar meningomyelocele had been closed immediately after birth in 1 boy.

Syringomyelia was detected at all levels of the spinal cord. Intradural adhesions were found only in the region of the thoracic spine, and most frequently in the upper thoracic spine. All 3 adhesions that were detected at T-12 were traumatic.

In none of the patients with syringomyelia were standard MR imaging studies able to demonstrate the level of CSF flow obstruction. In patients without syringomyelia, the presence of spinal cord compression, displacement, or caliber changes always suggested the location of a cyst on standard MR imaging studies.

During all 31 surgical procedures, CSF flow obstruction was detected at the level identified by phase-contrast MR imaging (Fig. 1). We gained access via hemilaminectomy in 22 cases, extended interlaminar fenestration in 6 cases, and the existing laminectomy in 3 cases.

Despite sufficiently high resolution (Fig. 2), useful diagnostic information was not obtained in 2 cases (during the first 5 procedures) as a result of poor-quality MurphyScope images. After a few minor technical problems with the endoscope adapter and the camera had been resolved, we were able to improve image quality. In 29 procedures, the image quality was sufficient and it was possible for the operating surgeon to assess the adjacent subarachnoid space for the presence of adhesions and CSF flow obstructions (Fig. 3). In the first 5 cases, operative times increased by an average of 15 minutes. This extra time was reduced from 20 minutes in the beginning to 10 minutes by the end of the series. In 17 cases, a median septum was detected between the spinal cord and the arachnoid. Because it extended in the direction of CSF flow and did not obstruct CSF pulsations, however, it was considered to be physiological.

In 6 cases, the surgeon identified further adhesions that were obstructing CSF flow and were located in the adjacent subarachnoid space. This region could not be

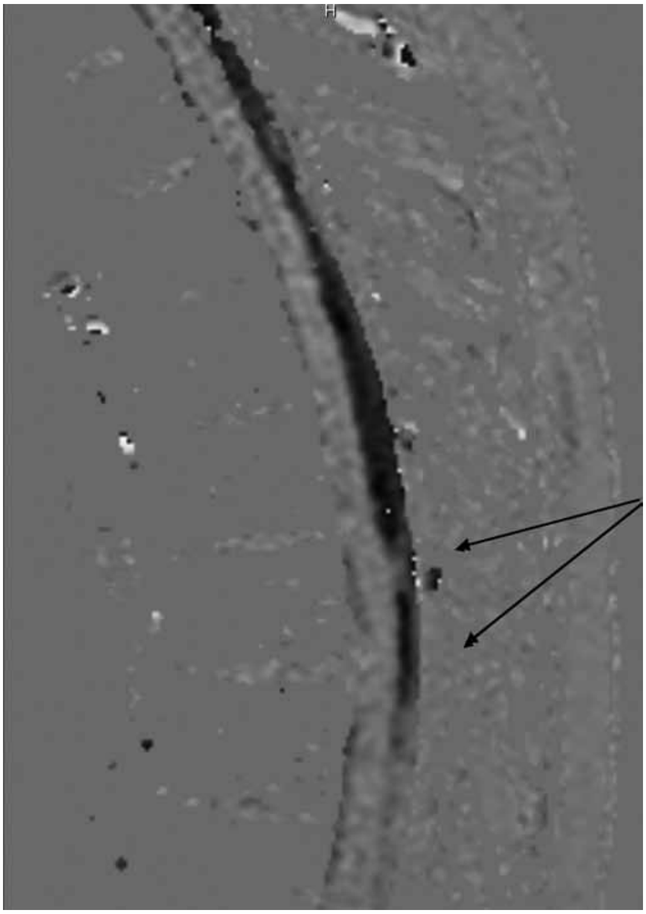

**Fig. 1.** Preoperative phase-contrast MR image showing an adhesion in the spinal cord *(arrows)*.

**Fig. 2.** Example of the resolution of a MurphyScope image, showing the text on a suture package.

visualized with the microscope. The surgeon did not, however, attempt to advance the MurphyScope past these adhesions. Instead, he enlarged the incision in the ligamentum flavum, removed as much bone as required, and opened the dura mater to expose the previously undetected adhesions. In all 6 cases, the endoscopically identified adhesions were noted and removed during microsurgery. In 1 case, the exposure had to be extended by 1 complete vertebral level via an additional hemilaminectomy. In all other cases, an enlargement of the incision and the removal of adjacent bone tissue were sufficient. In 3 of these 6 patients, we observed a rapid and persistent decrease in syrinx size. Two of these patients developed new adhesions in the area of exposure and required further surgery. One of the patients without syringomyelia had a favorable course. In summary, all patients who required an extended exposure on the basis of the endoscopic findings initially benefited from surgery.

The MR imaging studies that were performed in the 1st postoperative week demonstrated free CSF flow in all patients. In 18 of the 22 patients with syringomyelia, MR imaging revealed a decrease in syrinx size (Fig. 4). In the remaining 4 patients with this disorder, MR imaging studies demonstrated free CSF flow but no marked decrease in the size of the syrinx. In all 6 patients without syringomyelia, the spinal cord appeared decompressed.

Two patients required revision of the operative site for a persistent collection of CSF during the first 4 weeks. Prior to the procedure in our hospital, 1 of these patients had undergone surgery at another institution. In only 1 case did we observe a persistent deterioration in a patient's neurological condition; however, this was not clinically relevant. In 1 patient with posttraumatic incomplete paraplegia, the sensitive area of 1 leg was persistently larger after surgery. One patient experienced a superficial wound-healing problem. Intensive wound management was administered and the wound healed well; no deep

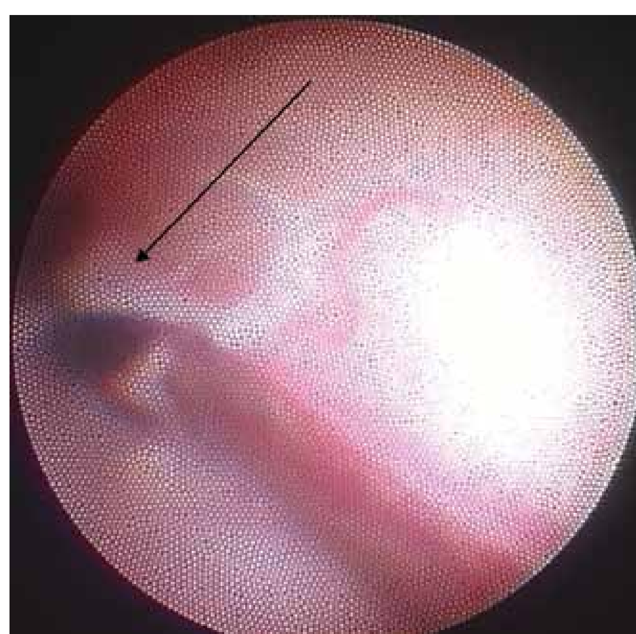

**Fig. 3.** Endoscopic image of an adhesion *(arrow)* located 2 cm cranial to the site of microsurgery. A small area where CSF flow is unobstructed can be seen on the left side of the image.

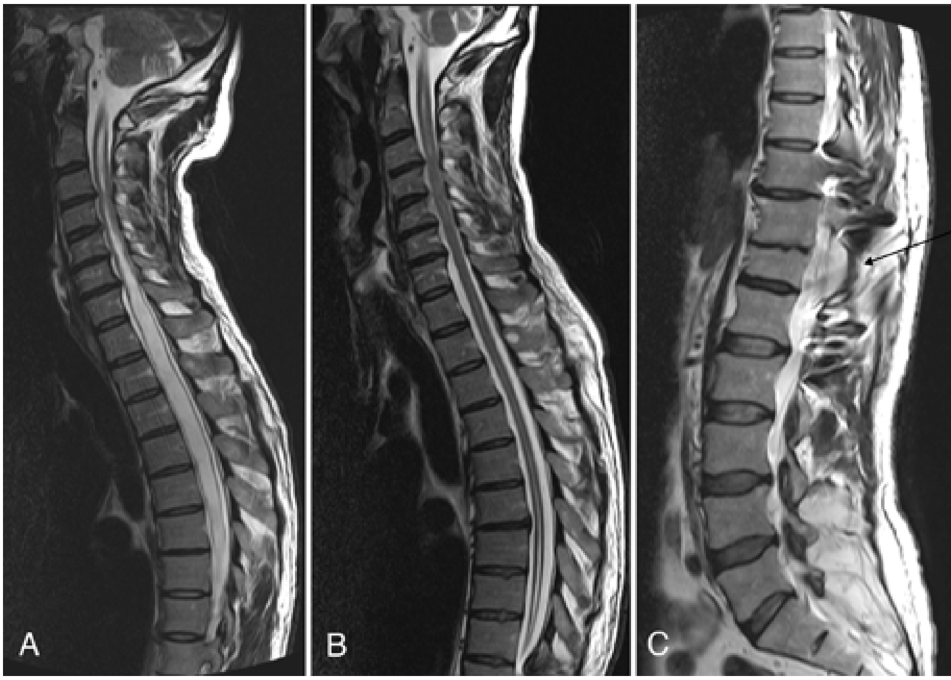


**Fig. 4.** **A:** Sagittal T2-weighted MR image demonstrating the presence of a syrinx and adhesions caudal to the syrinx (not visible in this image). **B:** Postoperative sagittal T2-weighted MR image (same patient as in panel A) demonstrating the collapse of the syrinx on Day 5 after surgery. **C:** Postoperative sagittal T2-weighted MR image (same patient as in panel B) demonstrating the duraplasty *(arrow)* on Day 5 after surgery.

infection occurred, and no revision was required. There were no other relevant complications, and in particular no cases of meningitis, thrombosis, or death. The complication rate was thus 13% (4 of 31 procedures).

During a mean follow-up period of 2 years (median 3 years, range 1–5 years), no change in syrinx size was noted in the 4 patients who did not show a decrease in the size of the syrinx cavity after surgery. Four patients with a marked decrease in syrinx size developed new adhesions and required further surgery. Each of these patients had previously undergone intradural surgery; 3 had undergone intradural surgery at another institution (2 of whom had developed postoperative infection), and 1 had undergone surgery for a meningomyelocele. Two of these revision surgeries took place during the study period, and were thus performed with endoscopic assistance. Over a period of 2.5 years, another patient showed an increase in syrinx size and free CSF flow in the treated area, and developed a new relevant CSF flow obstruction 5 vertebral levels below the surgical site. Accordingly, the recurrence rate was 14% (4 of 28 patients).

## Discussion

As early as the end of the 20th century, endoscopic spinal intradural procedures were described as new surgical methods in a few publications,[10,14] which, however, referred to individual cases of application. Arachnoscopy has not become established as a routine procedure. In the majority of cases, flexible ultrathin endoscopes are used.[7,12,14,27,28] Statistical methods allowed Zaaroor et al.[31] to show that an endoscope designed to be used within the spinal intradural space must be smaller than 2.5 mm in diameter.

In particular, the endoscopic examination and treatment of syrinx cavities have been repeatedly described in the past.[7,12,14] According to the current understanding of the pathophysiological mechanisms of syringomyelia, however, this is not an effective approach to treatment.[17] In 3 of 4 patients who underwent percutaneous endoscopic placement of a syringopleural shunt, Guest et al.[9] had to convert the procedure to an open laminectomy. To our knowledge, there is only one other publication describing the adjunctive use of an endoscope for the inspection of the subarachnoid space during microsurgery for the causal management of syringomyelia.[8] During microsurgical procedures in 6 patients with intradural arachnoid cysts, Endo et al.[8] used a flexible endoscope to inspect areas that could not be visualized otherwise. In 3 patients, they also resected adjacent adhesions endoscopically. Such cases, however, are associated with the highest risk of injury to the spinal cord or a spinal artery. When we investigated the use of flexible ultrathin endoscopes, we found that image quality was insufficient. In addition, the use of flexible endoscopes carries a considerable risk of a spinal cord lesion caused by the rear parts of the instrument, which cannot be seen by the surgeon.

Some authors favor the percutaneous insertion of an endoscope through a Tuohy needle.[7,28] Shimoji et al.[26] reported that they successfully advanced a fiberscope to the fourth and third ventricles via a percutaneous route. Karakhan et al.[14] described different approaches, including a dorsal paramedian approach to the intradural space via interlaminar fenestration or hemilaminectomy. Woods et al.[30] used the same type of endoscope as we did in the study presented here, and performed endoscopy to diagnose tethered cord syndrome prior to wide exposure of the dura.

The rate of complications in our patients (13%) is similar to that in larger series. Klekamp et al.,[15] for example, reported a rate of 24% in 51 patients after microsurgery. At least it can be said that endoscopic assistance does not increase the rate of complications.

A recurrence rate of 14% for all patients after a mean period of 2 years is acceptable compared with other series.[15] All patients who required revision surgery had undergone previous surgery, and some of them had developed subsequent infections. Klekamp et al.[15] observed a long-term recurrence rate of 83% in patients with extensive scarring, and 45% in patients with minor scarring. Poor outcomes were reported by Dolan[6] in 17% of the patients (7 of 41) who underwent arachnoid dissection and duraplasty, and by Shikata et al.[25] in 22% of the patients (8 of 36) who underwent arachnolysis. It was interesting to note that Shikata et al. observed a better clinical outcome in patients who also underwent a fusion of the treated segment. In our series, the follow-up period is too short to conclude that we obtained better outcomes in our patients. Klekamp et al. reported, however, that almost all recurrences occurred within the 1st year after causal surgery, which consisted of lysis of intradural adhesions via laminectomy. After that period, stabilization was achieved. In our study, too, recurrences occurred within the 1st postoperative year after an excellent initial outcome.

Of course, we cannot answer the question whether the endoscopically detected adhesions were the cause of syringomyelia or whether it would have been sufficient to remove the adhesions that were visualized with the microscope. In addition, we must admit that the risk of spinal cord injury increases with the distance from the site of the opening, and that the rigid technique itself limits the area that can be evaluated. In our opinion, endoscopic therapy—unlike endoscopic diagnosis—is not safe at present, and can entail risks.

## Conclusions

Arachnoscopy is a safe, simple, and effective tool for use in microsurgical procedures, and is associated with good immediate postoperative results. An enlargement of the access site can prevent an early revision in some patients. An improvement in long-term outcome, however, cannot yet be proven.

### Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Mauer. Acquisition of data: Mauer, Gottschalk, Schulz. Analysis and interpretation of data: Mauer, Gottschalk, Schulz. Drafting the article: Mauer. Critically revising the article: Kunz, Schulz. Reviewed final version of the manuscript and approved it for submission: Mauer, Kunz. Statistical analysis: Mauer. Administrative/technical/material support: Gottschalk, Kunz. Study supervision: Kunz.

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# Complete endoscopic removal of colloid cyst using a nitinol basket retriever

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Neuroendoscopic treatment of colloid cysts is limited by the reach and flexibility of the instruments that can be passed through the working channels of the rigid neuroendoscope. The authors describe a case of a third ventricular colloid cyst where a large solid colloid fragment was recovered using a nitinol stone retrieval basket as a flexible wall-guided atraumatic salvage instrument. A flexible nitinol stone retrieval basket was successfully used through an endoscopic working channel to retrieve a large portion of the colloid cyst from the occipital horn of the lateral ventricle in a 70-year-old man who presented with progressive memory loss, urinary incontinence, and slowness of gait. A flexible nitinol stone retrieval basket can be safely and effectively maneuvered in the ventricular system, using the ventricular wall for deflection, and can be used to retrieve colloid cyst fragments as a salvage technique. Remaining free-floating large colloid cyst fragments in the ventricular system do not necessarily require a second craniotomy or bur hole for access but may be retrieved using a nitinol stone retrieval basket. *(DOI: 10.3171/2011.1.FOCUS10318)*

**Key Words** • **colloid cyst** • **endoscope** • **intraventricular cyst** • **endoscopic technique**

Colloid cysts of the third ventricle are uncommon lesions with a wide spectrum of natural histories. Most patients have an insidious course, as symptoms are mostly related to the development of hydrocephalus. Some patients present with sudden neurological deterioration, such as drop attacks, life-threatening acute hydrocephalus, and sudden death.[5,6,9] The reported incidence is 3.2 per 100,000 population.[9]

A number of surgical approaches for symptomatic colloid cysts exist. Open microsurgical excision techniques offer control and gross-total resection, but they require a larger access corridor.[2,6,9,13] Stereotactic aspiration or stereotactic-guided surgery has also been used.[11,12,14] The endoscopic approach for excision of colloid cysts is relatively recent and offers the advantage of excellent visualization and a minimally invasive corridor through the naturally dilated ventricular system. A more controlled resection of the cyst is possible through this approach, avoiding damage to critical structures in the anterior third ventricle.

Complete endoscopic resection of a colloid cyst can be difficult, but near-total excision can be achieved even with a single port or with the use of conventional endoscopic techniques.[3,7,8,14,17] During endoscopic resection, unforeseen situations can arise. We describe a case in which a large fragment of solid colloid was freely floating and eventually settled in the occipital horn, out of reach of the endoscopic catheters. Retrieval of the fragment would have at least required a second port if not conversion to open surgery. We chose to use a flexible nitinol stone retrieval basket, which is commonly used in urological procedures. This novel technique allowed for the retrieval of all fragments and ultimately resulted in complete resection of the cyst.

## Case Report

*Presentation.* The 70-year-old man presented with progressive memory loss, urinary incontinence, and slowness of gait. A CT scan showed a large colloid cyst with hydrocephalus, which was confirmed on MR imaging (Fig. 1A). After discussing the various treatment options, the patient elected to undergo endoscopic resection of the colloid cyst.

*Operation.* The patient's head was placed in a Mayfield headholder, and frameless navigation was registered. The right frontal scalp was prepared and draped, and the skin incision was made in the usual fashion. A bur hole was then made just anterior to the coronal suture 3.5 cm off the midline. After the trajectory was determined using frameless navigation, we used the Gaab endoscope (Karl Storz GmbH) and cannulated the right frontal ventricle.

The ventricle was inspected, and we could see that the septum pellucidum was widely fenestrated. The colloid cyst was visible through the right Monro foramen, and there was significant hydrocephalus (Fig. 1B). Using the endoscopic bipolar cautery, we coagulated back the choroid plexus at the Monro foramen, increasing our

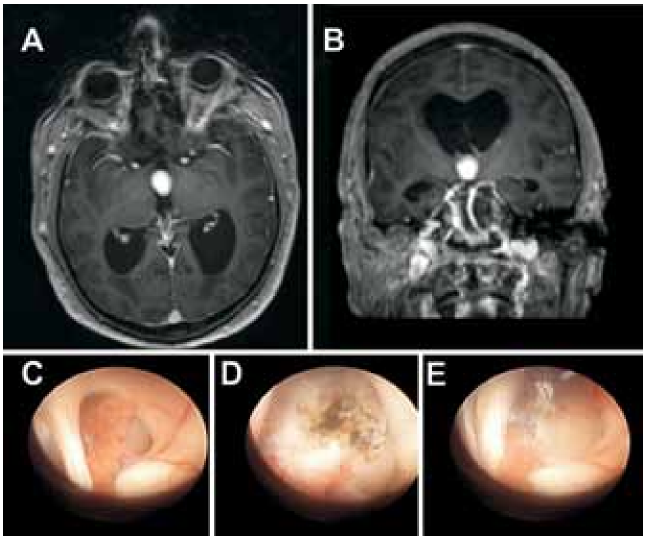


**Fig. 1.** **A and B:** Axial **(A)** and coronal **(B)** T1-weighted Gd contrast-enhanced MR images demonstrating the colloid cyst situated in the third ventricle and concomitant hydrocephalus. **C and D:** Endoscopic views of the right Monro foramen **(C)** and the visible portion of the colloid cyst in the third ventricle **(D)**. **E:** Endoscopic view showing penetration of the cyst wall using an Nd:YAG laser, creating multiple holes in the cyst wall. Manipulation of the cyst wall using a grasper is visible on the upper edge of the image.

exposure and visualization of the colloid cyst. We then used an Nd:YAG (neodymium-doped yttrium aluminum garnet) laser to perforate the colloid cyst capsule and create holes. It became clear that the content of the cyst was solid material (Fig. 1C).

We tried to aspirate cyst contents with the aid of a pediatric feeding tube that was fashioned into a suction cannula, but the material was too firm to be removed by suction. We then debulked the colloid cyst internally by using a combination of microcup forceps and alligator grasping forceps. Small fragments were removed, and periodically we stopped to irrigate the ventricles and the irrigation channel of the endoscope by using warm Ringer lactate solution.

Once we had debulked the central aspect of the cyst, we were able to grasp the capsule of the cyst and deliver it through the Monro foramen (Fig. 1D). Ultimately, the entire cyst could be rolled out from the Monro foramen, exposing a small vascular bundle leading to the cyst. This was coagulated with the endoscopic bipolar cautery and then cut with microscissors.

As the last cut on this small vascular stalk was made, the entire cyst contents with large fragments of solid colloid drifted down into the right occipital horn (Fig. 2A). With the endoscope angled backward in a posterior direction, the fragments were visible but not within reach of the grasping forceps due to the limited angulation the endoscope could achieve without causing harm to the brain parenchyma around the endoscope.

We then began to irrigate the ventricles, and this caused the colloid fragments to tumble in a circular fashion, breaking off pieces of colloid, which then came out of the irrigation exit port. We then used a 3 Fr Zero Tip Nitinol Stone Retrieval Basket (used for grasping of renal stones, Boston Scientific),[16] which opens to an outer diameter of about 16 mm (Fig. 2B). We passed the basket down into the occipital horn of the ventricle and used the snare to grasp the remaining portions of the cyst until all of its contents had been removed (Fig. 2C–F). We then irrigated the ventricles until they were perfectly clear. The scope was then removed, and the scalp was closed after placing a ventricular drain down into the right frontal horn of the ventricle and tunneling it out through a separate stab incision.

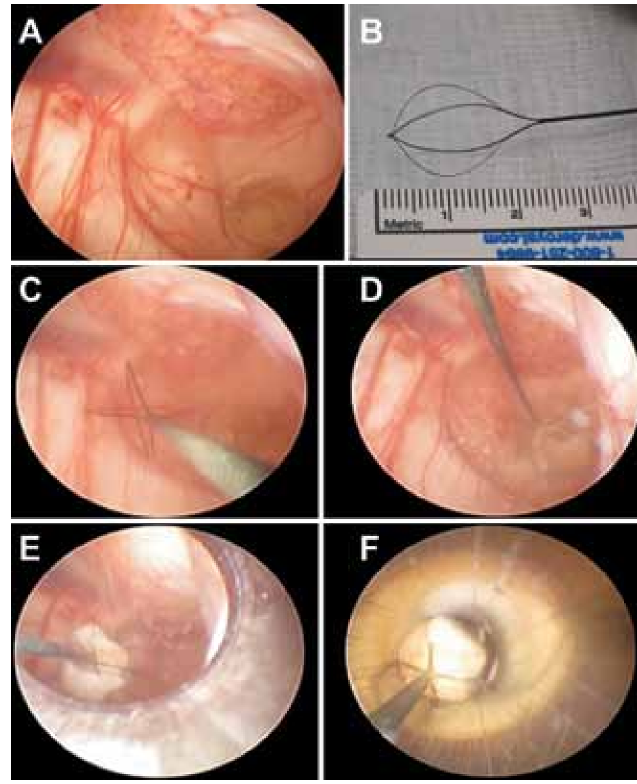


**Fig. 2.** **A:** Endoscopic view of the colloid cyst fragment in the occipital horn. **B:** Photograph of the self-expandable Zero Tip Nitinol Stone Retrieval Basket. **C–F:** Endoscopic views showing deployment of the nitinol basket in the lateral ventricle **(C)**, engagement of the colloid cyst fragment **(D)**, retrieval of the fragment in the lateral ventricle **(E)**, and in the endoscope inserter **(F)**.

## Results

We encountered the problem of a free-moving major fragment of the colloid cyst, resting due to gravity forces in the occipital horn of the lateral ventricle. Movement constraints and safety considerations allowed visualization of the cyst at the edge of the endoscopic field but not the use of conventional endoscopic instruments. We successfully used a flexible kidney stone basket that could be maneuvered in the ventricular system in an atraumatic fashion due to its rounded shape and flexible mounting shaft.

## Discussion

Patients with colloid cysts present with the classic triad of memory loss, gait abnormality, and incontinence, a symptom complex that can be indicative of normal-pressure hydrocephalus, which presents most often between the ages of 40 and 70 years.

The optimal surgical management of colloid cysts continues to be a matter of debate. Colloid cysts are benign lesions with a low risk of recurrence after radical resection. Open microsurgical excision was traditionally considered the gold standard treatment. However, operative approaches are not without risks. Of 38 patients in 1 series who underwent transcortical-transventricular resection of the colloid cyst, 30% had postoperative complications.[6] The transcallosal approach avoids the risks of a cortical incision, but it is associated with complications that include cortical venous infarction, forniceal damage, injury to the deep venous system, subdural hematoma, disconnection syndromes, ventriculitis, and meningitis.[1,2,9,14] Minimally invasive approaches sought to minimize the impact of surgery and include the stereotactic aspiration of the cyst contents.[4] However, not all colloid cysts are suitable for aspiration, high viscosity of the cyst contents limit the complete evacuation of cyst contents, and the capsule is always left behind.[11,12,15]

The goal of a procedure should be to perform a radical excision of the lesion if safely possible, and, although some neuroendoscopists[3,17] have advocated complete cyst wall excision to prevent cyst recurrence, the majority of patients with small residual remnants seem not to have a recurrence.[7,8]

Intraventricular endoscopic technique is by definition constrained by the walls of the ventricular system, and endoscopic instruments can use this constraint to their advantage; however, most neuroendoscopic instruments are rigid and steerable only by manipulating the angulation and depth of the endoscope itself. Thus, if a target structure cannot be centered in the line of sight of the endoscope, it cannot be reached by traditional endoscopic instruments. The ventricular wall cannot be used to deflect instruments due to the risk of tearing and damaging the underlying brain parenchyma, potentially causing fatal bleeding. An instrument that takes advantage of the ventricular wall as a deflector has to be flexible and must have an atraumatic shape.

Nitinol, a metal alloy of nickel and titanium, exhibits 2 related and unique properties: shape memory and superelasticity (also called pseudoelasticity), which, coupled with its physiological and chemical compatibility with the human body, have made it one of the most commonly used materials in medical device engineering and design.[10] In the case of the stone basket retriever (Fig. 2A), it allows the prompt expansion of the basket from its sheath and the control of its size by partial resheathing. In its fully expanded form, the basket is atraumatic and can be safely maneuvered along the ependyma of the ventricle. Collapsed in its thin sheath, it can be inserted through the working side ports of the endoscope. We chose the Zero Tip Nitinol Stone Retrieval Basket over other available retrieval devices precisely for its lack of a leading tip that could potentially penetrate the ventricular wall and cause injury. In its expanded form, this device has no sharp edges impeding axial movements because it is made of nitinol, which is flexible enough to allow manipulation in the ventricular system.

We present a single case in which we achieved a complete resection of a colloid cyst using a completely endoscopic approach. With the innovative use of a flexible nitinol kidney stone retrieval basket, we were able to manage the problem of a free cyst fragment, which dislodged and settled in the occipital horn of the lateral ventricle and out of the reach of the straight rigid endoscopic instruments. We would like to think of this technique as an option that may become a useful part of the neurosurgeon's armamentarium as a salvage technique and for the retrieval of large cyst fragments in a planned fashion toward the end of the procedure.

Complete endoscopic resection may require a certain skill and the requisite learning curve. Multiple techniques that can be helpful have been described,[3] and the neurosurgeon's armamentarium should include a variety of techniques to address issues that maybe encountered (for example, hardened cyst contents not amenable to suction as described in our case).

## Conclusions

Remaining free-floating large colloid cyst fragments in the ventricular system do not necessarily require a second craniotomy or bur hole for access but may be retrieved using a kidney stone basket. More experience with this technique is required before advocating it as part of a planned resection strategy, but we believe that this is a low-risk technique that can save the patient from a second craniotomy or bur hole when used as a salvage strategy.

#### Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Schirmer. Acquisition of data: both authors. Analysis and interpretation of data: both authors. Drafting the article: Schirmer. Critically revising the article: both authors. Reviewed final version of the manuscript and approved it for submission: both authors. Administrative/technical/material support: Heilman.

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# Early endoscope-assisted hematoma evacuation in patients with supratentorial intracerebral hemorrhage: case selection, surgical technique, and long-term results

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*Object.* Currently, the effectiveness of minimally invasive evacuation of intracerebral hemorrhage (ICH) utilizing the endoscopic method is uncertain and the technique is considered investigational. The authors analyzed their experience with this method in terms of case selection, surgical technique, and long-term results.

*Methods.* The authors performed a retrospective analysis of the clinical and radiographic data obtained in 68 patients treated with endoscope-assisted ICH evacuation. Rebleeding, morbidity, and mortality were recorded as primary end points. Hematoma evacuation rate was calculated by comparing the pre- and postoperative CT scans. Glasgow Coma Scale scores and scores on the extended Glasgow Outcome Scale (GOSE) were recorded at the 6-month postoperative follow-up. The technical aspect of this report explains details of the procedure, the instruments that are used, the methods for hemostasis, and the role of hemostatic agents in the management of intraoperative hemorrhage. The pertinent literature was reviewed and summarized.

*Results.* All surgeries were performed within 12 hours of ictus, and 84% of the surgeries were performed within 4 hours. The mortality rate was 5.9%, and surgery-related morbidity occurred in 3 cases (4.4%). The hematoma evacuation rate was 93% overall—96% in the putaminal group, 86% in the thalamic group, and 98% in the subcortical group. The rebleeding rate was 1.5%. The mean operative time was 85 minutes, and the average blood loss was 56 ml. The mean GOSE score was 4.9 at 6-month follow-up. The authors acknowledge the limitations of these preliminary results in a small number of patients.

*Conclusions.* The data suggest that early endoscope-assisted ICH evacuation is safe and effective in the management of supratentorial ICH. The rebleeding, morbidity, and mortality rates are low compared with rates reported in the literature for the traditional craniotomy method. This study also showed that early and complete evacuation of ICH may lead to improved outcomes in selected patients. However, the safety and efficacy of endoscope-assisted ICH evacuation should be further investigated in a large, prospective, randomized trial.
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**Key Words** • **endoscopic surgery** • **intracerebral hemorrhage** • **minimally invasive surgery** • **surgical result**

Surgical management of ICH is still a matter of controversy with regard to indications, timing, and method. In patients with ICH, conventional craniotomy has a mortality rate of 22%–36%, and 44%–74% of patients who undergo the procedure have poor outcomes.[6,15] Recent reports have shown that the endoscopic evacuation of ICH is safe and effective and may have some advantages over traditional craniotomy.[3,9] However, supporting evidence from controlled trials is lacking, and according to the AHA/ASA Guidelines for the Management of Spontaneous Intracerebral Hemorrhage, the effectiveness of minimally invasive ICH evacuation utilizing the endoscopic method is still uncertain and the technique considered investigational.[5] Therefore, we present our series of cases involving patients with supratentorial ICH who underwent endoscope-assisted hematoma evacuation and discuss case selection, surgical technique, and long-term results.

*Abbreviations used in this paper:* AHA = American Heart Association; ASA = American Stroke Association; EVD = extraventricular drain; GCS = Glasgow Coma Scale; GOSE = extended Glasgow Outcome Scale; ICH = intracerebral hemorrhage; ICP = intracranial pressure; IVH = intraventricular hemorrhage.

* Drs. Kuo and Chen contributed equally to this work.

## Methods

*Surgical Indications and Patient Selection*

To qualify for inclusion in this study, patients had to have the following: 1) a putaminal ICH with a hematoma volume greater than 30 ml; 2) a thalamic ICH with a hematoma volume greater than 20 ml and IVH with acute hydrocephalus; or 3) a subcortical hemorrhage greater than 30 ml with significant mass effect (midline shift greater than 5 mm and effacement of perimesencephalic cistern) and neurological deterioration. In addition they had to have undergone surgery within 12 hours after ictus for inclusion in this study.

Patients who were younger than 45 years or had no history of hypertension underwent contrast CT and CT angiography to exclude the presence of a vascular lesion or tumor. The study exclusion criteria were ICH caused by tumor, trauma, coagulopathy (prothrombin time > 12.2 seconds, partial thromboplastin time > 35.5 seconds, platelet count < 100 × $10^3$/μl), aneurysm, or arteriovenous malformation. Patients taking antiplatelet or anticoagulation medications as well as those with end-stage renal disease or with Child Class C liver cirrhosis were also excluded. Patients with preoperative GCS scores less than 4 or greater than 13 were excluded. In addition, patients who did not have a follow-up CT scan within 3 days after surgery or were lost for follow-up at 6 months were all excluded in this study.

*Surgical Technique, Caveat, and Management of Intraoperative Bleeding*

For most putaminal ICHs, we use the transtemporal approach (or the "temporal" approach mentioned by Hsieh et al.[4]). (The "frontal" approach is used only when the frontal route provides the shortest distance between the cortical surface and the hematoma on the preoperative CT scan.) In patients with hemorrhage on the left or dominant side, we use the transcortical corridor through the inferior temporal gyrus. In patients with right- or nondominant-side ICH, we use the corridor that traverses the shortest distance to the hematoma (judging from the preoperative coronal CT scan).

In patients with a thalamic ICH, the goal is to alleviate the acute hydrocephalus and elevated ICP while removing the IVH and ICH as much as possible without causing further damage to the brain parenchyma. Therefore, we use the ipsilateral Kocher point as our entry point. In patients with massive IVH, a flexible endoscope may be used with the free-hand technique to evacuate the blood in the third and fourth ventricles.[5] In addition, bilateral EVD placement may be considered in these cases. If the ventricle is entered during surgery, an EVD will be inserted through the operative tract.

With the patient in a state of general anesthesia, a linear skin incision (3–4 cm in length) is created. A 1.5- to 2.0-cm bur hole is then created with the dura opened in cruciate fashion. A small corticotomy is created, and the custom-made transparent plastic sheath (10 mm in outer diameter; length 5, 7, 9, 12, or 15 cm depending on the length needed estimated from the preoperative CT scan; [Fig. 1]) was inserted along with the stylet. This step can be done under real-time ultrasound guidance (Aloka UST- 5268P-5 neurosurgery bur hole probe, 3.0–7.5 MHz, phased-array sector probe) if that is the surgeon's preference. After removal of the stylet, the 4-mm 0° rod-lens endoscope with irrigation system (18 cm in length; Karl Storz) was introduced into the transparent sheath to provide visualization during hematoma removal. Depending on the surgeon's preference, the surgeon may hold the sheath and the endoscope together in his or her right hand, or the assistant may hold the sheath.

Our concept of hematoma removal is depicted in Fig. 2. In our experience, it is prudent to avoid damaging the brain parenchyma with excessive manipulation of the sheath. This can be accomplished by removing the most distal part of the hematoma first and as the sheath is gradually withdrawn the residual hematoma will be pushed into the tip of the sheath as the brain expands. This is in contrast to the traditional craniotomy method that follows the brain parenchyma–hematoma junction during hematoma evacuation to ensure complete hematoma evacuation. The hematoma is evacuated by manipulating the suction through the working space within the sheath. Alternatively, a flexible endoscope (outer diameter 2.5 mm; Karl Storz) could be introduced into the transparent sheath to facilitate hematoma removal without significant rotation or excessive manipulation of the sheath within the brain parenchyma. Using this technique, large and elliptical putaminal ICHs can be evacuated through the temporal approach (instead of the frontal approach[4]) with a high rate of hematoma evacuation.

In our experience, about 70% of ICHs could be evacuated without an obvious or active bleeder being identified intraoperatively. In these cases, the operation was very straightforward and usually could be done within 60 minutes. However, when bleeding occurs, patience is needed

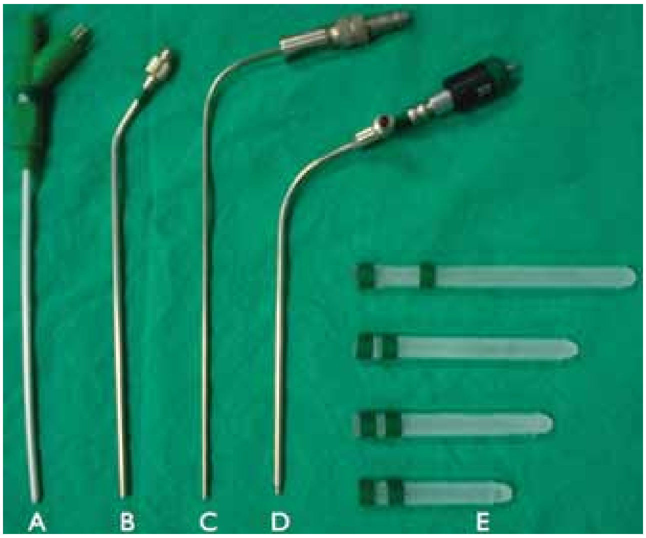


**Fig. 1.** Instruments used for endoscope-assisted hematoma evacuation. **A:** Bipolar suction coagulator (11 Fr, 14 or 19 cm in length, flexible, disposable; Kirwan Surgical Products). **B:** Specialized 3-mm flexible catheter created to deliver Floseal to the identified bleeder. **C:** Regular angled suction tube (8 Fr). **D:** Unipolar suction-coagulation tube (3 mm, Karl Storz). **E:** Sheaths, 10 mm in outer diameter with various lengths (shown here: 5, 7, 9, and 12 cm).

and some technique must be applied to ensure hemostasis. Bleeding from a small artery or perforating vessel can be secured with repeated irrigation for 2–5 minutes. This is the so-called "wait-and-see saline irrigation" method that is a basic technique of neuroendoscopic surgery. If this does not stop the bleeding, the bleeder must be identified using the balanced irrigation-suction technique, which is elegantly described by Nagasaka et al.[8] With constant irrigation and point suction, the bleeder can usually be identified. The bleeder is then meticulously caught and held by the suction cannula under low-pressure suction. It is then coagulated using a flexible, disposable bipolar suction coagulator (11 Fr, 14 or 19 cm in length; Kirwan Surgical Products; Fig. 1), which performs coagulation and suction simultaneously. The use of hemostatic agents such as Floseal (Baxter) is another alternative. A specialized 3-mm flexible catheter was created to deliver Floseal to the identified bleeder (Fig. 1B). In our series, most bleeding from these perforators stopped after gentle compression with cotton and irrigation for 2 minutes (Fig. 3). After hematoma removal and meticulous hemostasis, we do not insert a drainage tube into the hematoma cavity. An ICP monitor, however, may be inserted as needed.

*Clinical and Radiological Follow-Up*

All patients underwent a follow-up CT scan within 3 days after surgery. The hematoma evacuation rate in each patient was then calculated as follows: ([preoperative hematoma volume – postoperative hematoma volume]/preoperative hematoma volume) × 100%. Rebleeding, morbidity, and mortality were recorded as primary end points. The GOSE score was recorded at 6-month postoperative follow-up either at an outpatient clinic and/or by telephone survey.

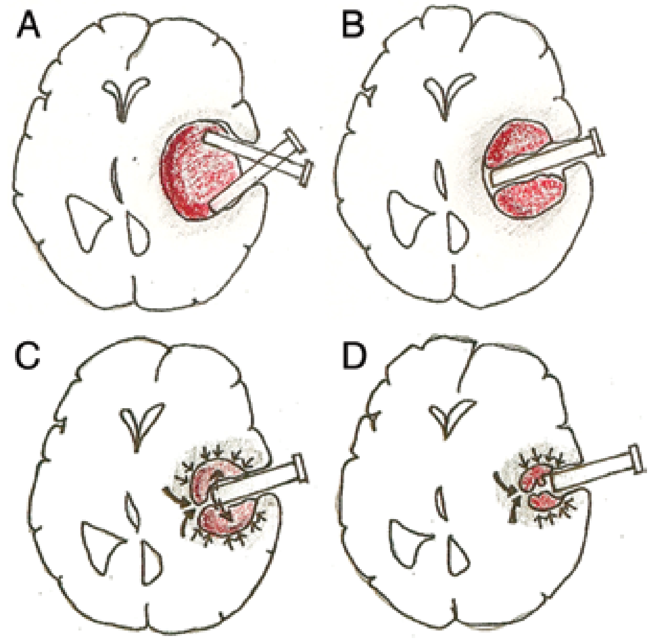


**Fig. 2. A:** Traditional method of endoscope-assisted ICH evacuation. Hematoma clearance should follow the hematoma–brain junction. Note that the brain is susceptible to damage due to the angle of the sheath. **B:** Our concept of hematoma evacuation, in which suction is directly applied through the long axis of the hematoma until the normal brain surface appears. The depth of the working length can be accurately estimated on preoperative CT scans. **C:** On gradual withdrawal of the sheath, the adjacent residual hematoma is pushed by the expanding brain to the tip of the sheath. The hematoma can be easily and safely evacuated. The angle of the sheath can remain more limited (to avoid damaging the brain). Using this method, the brain tissue injured by the sheath would be significantly less than in the traditional method. **D:** As the sheath is withdrawn, the hematoma cavity collapses and the residual hematoma is pushed into the tip of the sheath.

## Results

Between January 2008 and June 2010, 198 patients with ICH were treated at National Taiwan University Hospital Yun-Lin branch and Chang-Hau Christian Hospital. According to the aforementioned inclusion and exclusion criteria, 68 patients who underwent endoscopically assisted ICH evacuation were included in this study. This group included 48 men and 20 women (mean age 63 years, range 42–82 years). There were 35 cases of putaminal ICH (51.5%), 24 cases of thalamic ICH (35.3%), and 9 cases of subcortical ICH (13.2%). All patients underwent surgery within 12 hours of ictus, and 57 patients (84%) underwent surgery within 4 hours. The mean time from ICH onset to surgery was 5.8 hours. The mean operative time was 85 minutes and the average blood loss was 65 ml.

Table 1 summarizes the surgical and functional outcomes in patients with putaminal, thalamic, and subcortical ICH. The hematoma evacuation rate was 93%—96% in the patients with putaminal ICH, 86% in those with thalamic ICH, and 98% in those with subcortical ICH. The mortality rate was 5.9% (4 of 68 patients); 2 patients died of pneumonia and sepsis, 1 died of ischemic bowel and multiorgan failure, and 1 died of cardiogenic shock from suspected acute myocardial injury. Surgery-related morbidity occurred in 3 cases (4.4%): 2 patients had wound infections and 1 had rebleeding. Therefore, the rebleeding rate is 1.5%. The patient with rebleeding was a 62-year-old man with a left putaminal hemorrhage whose GCS score improved gradually after surgery (initial GCS score was 8 and GCS score 1 week after surgery was 13). However, rebleeding occurred 10 days after surgery and his GCS score dropped to 6. The patient underwent repeated surgery using the endoscope-assisted method and his condition improved postoperatively. His GCS score was 12 at 6-month follow-up, but there was no improvement in his right hemiplegia.

In terms of functional recovery, the mean preoperative GCS score was 7.1 and the mean GCS score 1 week after surgery was 11.0. The mean GCS score at 6-month follow-up had improved to 11.6. The mean GOSE score at 6-month follow-up was 4.9.

## Discussion

*Outcome Improvement With Early and Complete Hematoma Evacuation*

Due to the good clinical, radiological, and functional outcomes seen in this series, it is suggested that early and complete evacuation of ICH via a minimally invasive

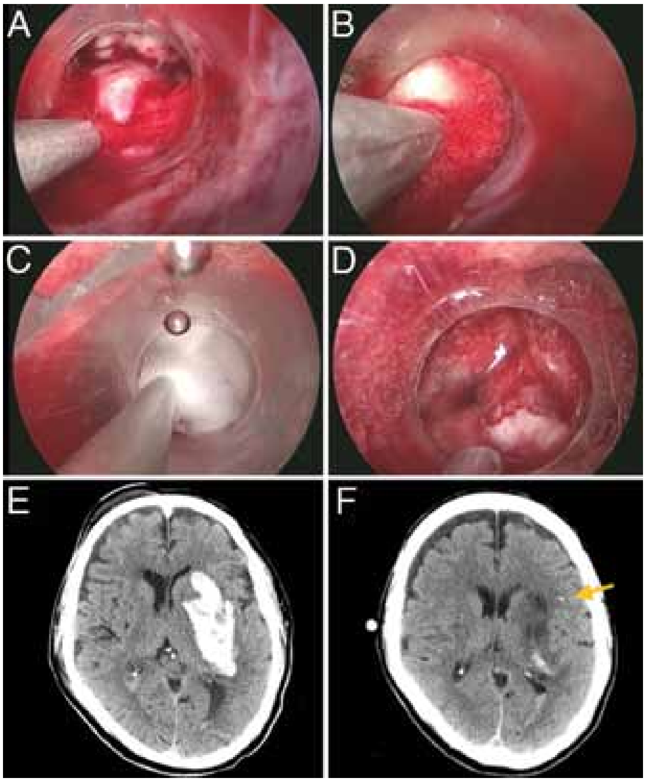


**Fig. 3.** Using a hemostatic agent in a case of putaminal hemorrhage. **A–D:** Intraoperative images showing the use of the hemostatic agent. The bleeder is identified **(A)** and Floseal is applied to bury and pack the bleeder and adjacent tissue **(B)**. The bleeder is then covered with cotton and gentle pressure is applied with the suction tip while saline irrigation is performed **(C)**. Hemostasis is achieved after 2 minutes **(D)**, and saline irrigation is then used to wash out residual hemostatic agent. **E:** Preoperative axial CT scan showing the left putaminal ICH. **F:** Postoperative CT scan showing 5 ml of residual hematoma and the ICP monitor *(arrow)* that was inserted through the operation tract.

method may lead to improved outcome in these patients. One of the important findings of this study is that early surgery utilizing the endoscope-assisted method has a very low rebleeding rate. Since the hematoma contributes to local mass effect and elevated ICP and elicits pathological cascades that result in biochemical toxicity, it is plausible that early and complete removal of ICH via a minimally invasive method can reduce the secondary injury associated with ICH.[16] Theoretically, this should lead to improved functional outcomes and decreased mortality rates. According to the AHA/ASA Guidelines for the Management of Spontaneous Intracerebral Hemorrhage, no clear evidence at present indicates that ultra-early removal of supratentorial ICH improves functional outcomes or mortality rates. In addition, the authors mentioned that very early craniotomy may be harmful due to increased risk of recurrent bleeding. This recommendation was based on a trial of 11 patients randomized within 4 hours of hemorrhage onset, where rebleeding occurred in 40% of the patients treated within 4 hours compared with 12% of the patients treated within 12 hours using the craniotomy method.[7] On review of the literature, we found that endoscope-assisted ICH evacuation performed in the early stage was associated with a minimal rebleeding rate (0%–3.3%) compared with the traditional craniotomy method (5%–10%).[3,9] However, differences in patient selection, surgical indication, timing, technique, and perioperative care made direct comparison inappropriate and mandate the need for a randomized-controlled study to elucidate this point. Other advantages of the endoscope-assisted method include low complication rate, less operative time, less blood loss, improved evacuation rate, and early recovery of the patients. The results of our study further confirm these potential benefits compared with traditional craniotomy.

Second, endoscope-assisted ICH evacuation may provide a better hematoma evacuation rate with minimal damage to normal brain tissue. Due to the improvement of neuroendoscopic systems and instruments, recent series have shown high rates of hematoma evacuation that

**TABLE 1: Surgical and functional outcomes in patients with putaminal, thalamic, or subcortical ICH**

| Variable | Putaminal ICH | Thalamic ICH | Subcortical ICH | All |
|---|---|---|---|---|
| no. of patients | 35 | 24 | 9 | 68 |
| median hematoma evacuation rate (%) | 96 | 86 | 98 | 93 |
| rebleeding rate (%) | 2.8 | 0 | 0 | 1.5 |
| morbidity | | | | |
| no. of patients | 2 | 1 | 0 | 3 |
| rate (%) | 5.7 | 4.1 | 0 | 4.4 |
| mortality | | | | |
| no. of patients | 1 | 2 | 1 | 4 |
| rate (%) | 2.8 | 8.3 | 11.1 | 5.9 |
| mean GCS scores (range) | | | | |
| preop | 7.8 (4–14) | 5.8 (4–14) | 8.2 (6–12) | 7.1 (4–14) |
| 1 wk postop | 12.2 (3–15) | 8.9 (3–15) | 12.1 (3–15) | 11.0 (3–15) |
| 6 mos postop | 12.8 (3–15) | 9.8 (3–15) | 11.8 (3–15) | 11.6 (3–15) |
| mean GOSE 6 mos postop (range) | 4.8 (1–7) | 5.2 (1–7) | 4.9 (1–8) | 4.9 (1–8) |

ranged from 83.4% to 99%.[3,4,8–10,12] The hematoma evacuation rate in the present study is comparable to what has been reported in the literature. We do think that there is a trend toward a higher evacuation rate when the surgery is performed early (within 12 hours) due to the fact that, within this period, the clot is usually easily suctioned (in contrast to the treatment of subacute hematomas). This is in contrary to the common belief that delayed evacuation is technically simpler due to partial liquefaction of the hematoma. However, our experience is further supported by the experience of the authors of another large series who mentioned that "surgery should be performed within 24 hours after onset, because intracerebral hematoma usually starts to harden about 24 hours after onset and 48 hours later it can not be evacuated with a suction tube."[12] The lower evacuation rate in thalamic ICH is a reflection of our different philosophy toward its treatment. Although enthusiasm for surgical evacuation of thalamic ICH has been limited, we do think that relieving the acute hydrocephalus from IVH is necessary for better recovery. As mentioned previously, the IVH and thalamic ICH were evacuated as much as possible without damaging the brain parenchyma. We perform aspiration at the rupture site (Fig. 4), and we do not enter the thalamus in attempt to remove more clot. For this reason, the hematoma clearance rate was lower in patients with thalamic ICH (86%). In addition, patients with thalamic ICH usually recover more slowly than patients with subcortical or putaminal ICH (Table 1).

*Comparison With Different Methods of Endoscope-Assisted ICH Evacuation*

Several groups have developed methods of minimally invasive endoscope-assisted ICH evacuation.[1,3,4,8–14] Table 2 summarizes the surgical indications, timing, technique, and results of the endoscope-assisted methods of ICH evacuation as reported in different series.

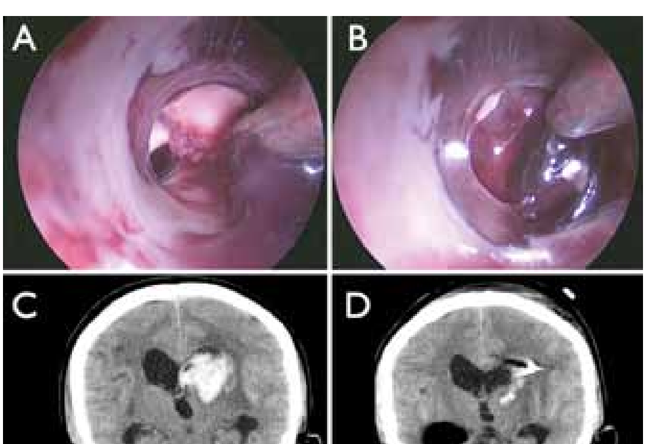


**Fig. 4.** Endoscope-assisted evacuation of left thalamic ICH and IVH with acute hydrocephalus. **A and B:** Intraoperative images showing evacuation of the IVH **(A)** and ICH **(B).** The IVH was evacuated through the sheath inserted through the ipsilateral Kocher point **(A)**. The ipsilateral foramen of Monro was seen after IVH evacuation. The ICH was evacuated through the rupture site on the thalamus **(B)**. We do not enter the thalamus for more complete hematoma evacuation. **C:** Preoperative coronal CT scan showing the left thalamic ICH and the IVH. **D:** Postoperative CT scan showing some residual hematoma and the EVD that was inserted through the operation tract.

However, it is difficult to directly compare the morbidity, mortality, and functional outcomes due to differences in patient selection, timing of surgery, technique, and perioperative care. Nevertheless, our outcome is comparable with that of other series. The major difference is the concept of hematoma evacuation that is depicted in Fig. 2. This concept of removing the most distal part of the hematoma first and having the residual hematoma collapse into the tip of the sheath decreases the need to stir or damage the brain by changing the angle of the sheath. It also avoids the early collapse of the hematoma cavity with residual hematoma that may need the inflation-deflation method to solve this problem.[8]

The selection of the approach (the frontal or temporal approach) for putaminal ICH is an important issue. Hsieh et al.[4] mentioned that, in patients with ICH volume less than 50 ml, it is not difficult to evacuate the hematoma through the shortest distance from the cortical surface to the hematoma. However, when the hematoma is larger than 50 ml, the shape usually became elliptical. The frontal approach was recommended by the authors in these cases due to its involving noneloquent regions and providing better visualization that may result in maximal hematoma evacuation. Our group used the temporal approach in most cases of putaminal ICH (29 [83%] of 35). The concept of hematoma evacuation was mentioned; it avoids excessive manipulation of the sheath and consequent damage to the brain parenchyma. If needed, flexible endoscopy may be used to evacuate the clot. When a bleeder is identified, the sheath is then pointed toward the bleeder for better visualization and secure hemostasis. The frontal approach may traverse the lenticulostriate perforators that may obscure visualization or even contribute to intraoperative bleeding. This may explain the high incidence of intraoperative bleeding (9 [82%] of 11 cases) in one series in which the frontal approach was used.[10] In our experience using the temporal approach for putaminal ICH, evacuation could be accomplished in approximately 70% of the cases without obvious intraoperative bleeding. The other advantage is the shorter working distance, which increases the comfort of the procedure and facilitates deftness. In cases in which a frontal approach is used, we usually create the bur hole in a more lateral position as mentioned by Suyama et al.[14]

Some authors advise that a posterior approach is better than an anterior approach for evacuating a thalamic hematoma and avoids injury to the intraventricular veins.[2,9,14] Nevertheless, we think that the approach chosen depends upon the extent of hematoma one plans to remove and the rupture site. As mentioned, our goal for these patients is to alleviate the elevated ICP and remove the IVH and ICH without causing further neuronal damage. Therefore, in most of our cases, we have chosen the anterior approach. There was no incidental injury of the venous structure in any of our cases.

With respect to other minor differences, we felt more confident using the suction bipolar coagulator instead of

**TABLE 2: Surgical indications, timing, technique, and results of the endoscopically assisted method for ICH evacuation in different series***

| Authors & Year | Indication | Timing | Pt Characteristics | Technique | Evacuation Rate | Rebleeding Rate | Long-Term Outcome† |
|---|---|---|---|---|---|---|---|
| Nishihara et al., 2000 | putaminal ICH vol >40 ml | median time to op: 3 hrs (range 1.5–11 hrs) | 9 pts w/ putaminal ICH | 10-cm-long rigid transparent sheath made of acrylic plastic attached to SS handle w/ round-tipped metal stylet | 86%–100% | NA | NA‡ |
| Nakano et al., 2003 | hematomas w/ vol >20 ml & <40 ml; putaminal ICH of small-intermediate size, hematoma situated deep in the brain (e.g., thalamic hemorrhage), intraventricular hematoma | NA | 7 pts; 4 w/ putaminal ICH, 2 w/ thalamic ICH, & 1 w/ subcortical hemorrhage; avg age 55 yrs | NA | NA | NA | NA§ |
| Suyama et al., 2004 | NA | 0–14 days | 48 pts; 32 w/ putaminal ICH, 9 w/ thalamic ICH, & 7 w/ lobar ICH | transparent sheath, hematoma cavity irrigated w/ artificial CSF | putaminal ICH 82%; thalamic ICH 76%; lobar ICH 82% | 2.0% | NA |
| Nishihara et al., 2005 | putaminal, thalamic, & subcortical ICH w/ vol >20 & cerebellar ICH w/ vol >15 ml w/ deterioration of consciousness | ultra-early op (w/in 3 hrs) for hemorrhages w/ vol >30 ml or hemorrhages causing impending herniation | 82 pts w/ ICH or IVH; 44 w/ putaminal ICH, 12 w/ thalamic ICH, 8 w/ subcortical ICH, 8 w/ cerebellar ICH, 10 w/ IVH | transparent sheath; hemostasis by electric coagulation at suction end; transparent cap attached to flexible endoscope provides clear visualization of op field during hematoma evacuation, which can prevent injury of ventricular walls | 96% (range 86%–100%) | no postop rebleeding | NA |
| Chen et al., 2005 | putaminal ICH vol >20 ml, GCS 5–12 w/ focal neurol deficit | 1–5 hrs (median 2 hrs) | 7 pts w/ hypertensive putaminal ICH; age range: 45–69 yrs | an 11-cm-long SS tube was adapted to serve as endoscopic sheath; op route along long axis of hematoma, requiring frontal approach | 90%–97% (median 93%); ICH vol 20–180 ml (median 78 ml) preop, 2–16 ml (median 6 ml) postop | no postop rebleeding | 6 pts were fully independent, including 4 who had no residual disability & 2 who had mod disability; 1 pt remained in a persistent vegetative state at clinical FU after 6 mos |
| Nagasaka et al., 2010 | putaminal ICH vol >31 ml, cerebellar ICH w/ diam >3 cm, or thalamic ICH w/ vol >20 ml & acute hydrocephalus | median time to op: 4 hrs | 23 pts; 15 w/ putaminal ICH, 6 w/ cerebellar ICH, 2 w/ thalamic ICH; mean age 61.4 yrs (range 36–85 yrs); mean preop GCS score: 7.2 (range 4–13) | a combination irrigation-coagulation suction cannula or multifunctional suction cannula was used | 99% | 0% | long-term outcome not mentioned, but the rate of good outcome (good recovery & mod disability) at discharge was 17.3% |

*(continued)*

**TABLE 2: Surgical indications, timing, technique, and results of the endoscopically assisted method for ICH evacuation in different series* *(continued)***

| Authors & Year | Indication | Timing | Pt Characteristics | Technique | Evacuation Rate | Rebleeding Rate | Long-Term Outcome† |
|---|---|---|---|---|---|---|---|
| present series | putaminal ICH vol >30 ml, or thalamic ICH vol >20 ml & IVH w/ acute hydrocephalus, or subcortical ICH vol >30 ml w/ sig mass effect & neurol deterioration | all ops performed w/in 12 hrs & 84% of ops performed w/in 4 hrs | 68 pts; 35 w/ putaminal ICH, 24 w/ thalamic ICH, & 9 w/ subcortical ICH; mean age 63 yrs (range 42–82 yrs); mean preop GCS score 7.1 (range 4–14) | transparent sheath, balanced irrigation-suction technique for identification of bleeder, coagulation w/ suction bipolar coagulator, hemostasis w/ Floseal; flexible endoscope used as an option | 93%; putaminal ICH 96%; thalamic ICH 86%; subcortical ICH 98% | 1.5% | mean GCS score was 11.6 & GOSE was 4.9 at 6-mo FU |

* avg = average; diam = diameter; FU = follow-up; mod = moderate; NA = information not available; neurol = neurological; Pt = patient; sig = significant; SS = stainless steel.
† At least 6 months postoperatively.
‡ All patients showed neurological improvement when they were examined 1 week after the procedure.
§ Good recovery in 50% of patients, but no details on long-term outcome.

the monopolar coagulator, and we do not place a drainage tube within the hematoma cavity after securing hemostasis. This study also demonstrates that the use of a hemostatic agent for noncoagulation hemostasis seems to be safe because the rebleeding rate was very low.

*Study Limitations*

We acknowledge the limitation of these preliminary results in this retrospective nonrandomized study. The patients in this study are highly selected and represent 34% of all ICH patients we have cared for in a 30-month period. Patients with a GCS score of 3, surgery after 12 hours from ictus, coagulopathy, or treatment with antiplatelet or anticoagulant therapy were excluded. These patients usually have a poor prognosis compared with the patients included in this study. Therefore, the good surgical outcomes and functional results may be due to patient selection.

## Conclusions

The results in our series of 68 patients indicate that early endoscope-assisted ICH evacuation is safe and effective in the management of supratentorial ICH. The rebleeding, morbidity, and mortality rates are low compared with rates reported in the literature for the traditional craniotomy method. This study also showed that early and complete evacuation of ICH may lead to improved outcomes in selected patients. However, these preliminary results warrant further study in a large, prospective, randomized trial in the near future.

#### Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Acquisition of data: Kuo, Chen, Chiu, Liu. Analysis and interpretation of data: Huang, Li, Tsai. Drafting the article: Huang, Kuo, Chen, Li, Tsai. Critically revising the article: Huang, Kuo, Chen, Tu. Reviewed final version of the manuscript and approved it for submission: Huang, Kuo, Chen, Tu. Study supervision: Tu.

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# Endoscopic endonasal transsphenoidal surgery for functional pituitary adenomas

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*Object.* The purpose of this study was to analyze preoperative predictors of endocrinological remission following endonasal endoscopic resection of therapy-resistant prolactin-, growth hormone (GH)–, and adrenocorticotropic hormone (ACTH)–secreting pituitary adenomas and to establish benchmarks for cure by using the most recent consensus criteria.

*Methods.* The authors reviewed a prospective database of 86 consecutive functional pituitary adenomas that were resected by a purely endoscopic endonasal transsphenoidal technique. Extent of resection was evaluated on postoperative contrast-enhanced MR imaging. Endocrinological remission was defined according to the most recent consensus criteria.

*Results.* The majority of functional adenomas (62.8%) were classified as macroadenomas (> 1 cm in maximum diameter), and 20.9% of lesions had invaded the cavernous sinus (CS) at the time of surgery. A gross-total resection was achieved in 75.6% of all patients. The rate of endocrinological remission differed between various types of functional adenomas. Cure rates were 92.3% (microadenomas) and 57.1% (macroadenomas) for prolactinomas, 75% (microadenomas) and 40% (macroadenomas) for GH-secreting tumors, and 54.5% (microadenomas) and 71.4% (macroadenomas) for ACTH-secreting tumors. Lower rates of cure occurred in GH-secreting macroadenomas due to a high rate of CS invasion, and in ACTH-secreting adenomas due to a high rate of lesions that were not visible on preoperative MR imaging. Whereas univariate analysis showed that macroadenoma, suprasellar, cavernous extension, or extent of resection correlated with cure, on multivariate analysis, only extent of resection and suprasellar extension predicted cure. One patient developed postoperative meningitis that was complicated by hydrocephalus requiring a ventriculoperitoneal shunt. Two patients developed postoperative panhypopituitarism, and 2 patients suffered from CSF leaks, which were treated with lumbar CSF diversion.

*Conclusions.* This paper reports benchmarks for endocrinological cure as well as complications in a large series of purely endoscopic pituitary surgeries by using the most recent consensus criteria. The advantages of extended endonasal approaches are most profound in tumors with suprasellar extension and CS invasion.

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**Key Words** • **endoscopy** • **acromegaly** • **prolactinoma** • **Cushing disease** • **minimally invasive surgery** • **transsphenoidal surgery** • **skull base**

The transsphenoidal approach for resection of a pituitary adenoma was first performed by Herman Schloffer more than 100 years ago.[37] Subsequently, the transsphenoidal approach created great interest, and a variety of modifications of this approach were described shortly thereafter. As discussed in a report by Henderson,[18] Harvey Cushing was the first to present a large clinical series of 231 transsphenoidal pituitary adenoma resections in 1939. However, because lack of adequate preoperative imaging made it impossible to foretell the size and configuration of the adenomas, he abandoned the procedure in favor of transcranial approaches. The majority of neurosurgeons followed Cushing's lead, and it was not until the advent of 2 technological milestones that the transsphenoidal technique resurfaced. First, the development of imaging techniques such as CT and MR imaging provided accurate information about the size and location of a lesion and allowed for appropriate patient selection and determination of the appropriate surgical access. Second, the introduction of the operating microscope and later endoscopy greatly improved intraoperative illumination and visualization. Although there are numerous studies reporting the endocrinological outcome following microsurgical

*Abbreviations used in this paper:* ACTH = adrenocorticotropic hormone; CS = cavernous sinus; GH = growth hormone; GKS = Gamma Knife surgery; GTR = gross-total resection; IGF-I = insulin-like growth factor–I; PRL = prolactin.

transsphenoidal resection of functional pituitary adenomas,[1,4–7,11,15,17,20,21,23,25,26,28,29,31,33,34,39,41,43–46] there is a paucity of literature reporting the endocrinological outcome following use of a purely endoscopic transsphenoidal technique.[8,12,19,36] Moreover, continuous re-evaluation of endocrinological outcomes following surgical treatment of functional pituitary lesions is necessary to keep up with the latest definitions of postoperative endocrinological remission. Based on improvements in follow-up data, criteria for endocrinological remission following resection have constantly evolved over time. Here we present our single-center experience in which we used the latest criteria for an endocrinological cure for PRL-, GH-, and ACTH-secreting adenomas[3,9,16] in a cohort treated with a purely endoscopic endonasal transsphenoidal technique.

## Methods

### *Patient Demographic Data*

We analyzed a prospectively collected database of all patients who underwent endoscopic endonasal surgery for a functional pituitary adenoma at Weill Cornell Medical College, New York–Presbyterian Hospital between February 2004 and June 2010, as a collaboration between the departments of Neurosurgery and Otolaryngology. Functional tumors were resected by the senior authors (T.H.S. and J.A.B.) using a purely endoscopic endonasal transsphenoidal approach. This study was approved by the institutional review board. For each operation, the duration of surgery, estimated blood loss, relevant laboratory values, adjuvant treatments, and complications were recorded.

### *Radiographic Evaluation*

Prior to resection, all patients underwent contrast-enhanced MR imaging. Tumor invasion of the CS was defined according to the following criteria: three-quarters or more encasement of the internal carotid artery, obliteration of the carotid sulcus venous compartment, or crossing of the lateral intercarotid line by the tumor.[10] Routinely, the surgical site was analyzed by contrast-enhanced MR imaging on postoperative Day 1, 3 months after surgery, and then at yearly intervals.

### *Surgical Technique*

Prior to surgery, all patients received antibiotics and glucocorticoids, and intrathecal fluorescein was used in 73% of cases to label CSF.[32] We use Brainlab neuronavigation for all of our cases. A detailed description of the procedure has been published previously.[19,24,35,38] Briefly, after application of topical cocaine to the nasal mucosa, the mucosa of the middle turbinates is infiltrated with a mixture of 1% lidocaine and epinephrine (1:100,000). The sphenoid ostia are identified bilaterally and enlarged by removal of bone. We then use a tissue shaver to resect the posterior third of the nasal septum. Using a high-speed drill and curettes, the anterior wall of the sella is opened. We attempt to resect microadenomas en bloc, whereas macroadenomas are first internally decompressed by removing the inferior portion of the tumor, followed by resection of the lateral portions. This maneuver prevents the suprasellar arachnoid from herniating down into the sella. Resection of extensive suprasellar components may require an extended approach to the lesions, including removal of the tuberculum sellae and planum sphenoidale.[24] Tumor is dissected off the medial CS wall. In case of CS invasion, the dura mater is opened medial to the internal carotid artery, and tumor can be easily removed from this area. Although it is also possible to open the CS lateral to the carotid, one must carefully weigh the safety of this maneuver with the increased extent of resection that it will facilitate, and how this will affect the long-term outcome of the patient, compared with treatment with stereotactic radiosurgery. The skull base defect is closed in a multilayered fashion.[27]

### *Endocrinological Evaluation*

All patients underwent pre- and postoperative endocrinological evaluation for free cortisol, ACTH, free thyroxine, thyroid-stimulating hormone, PRL, GH, IGF-I, testosterone, estradiol, luteinizing hormone, and follicle-stimulating hormone to assess for endocrinological derangements (except for 1 patient, who was lost to endocrinological follow-up). The diagnosis of a prolactinoma was made based on serum PRL levels of > 150 ng/ml in combination with typical clinical symptoms.[9] In patients with prolactinoma, endocrinological remission was defined as postoperative PRL levels of < 20 ng/ml in females or < 15 ng/ml in males. The diagnosis of Cushing disease was based on either abnormal 24-hour urinary free cortisol or abnormal results on low-dose dexamethasone suppression tests, defined as failure of 1 mg of dexamethasone to reduce plasma cortisol levels to < 1.8 μg/ml the next morning.[3,30] In Cushing disease, endocrinological remission was defined as an early morning cortisol level measurement of ≤ 1.8 μg/ml obtained within 48 hours after surgery or a normalization of the 24-hour urinary free cortisol.[3] The diagnosis of acromegaly was based on abnormal basal fasting levels of GH and IGF-I.[16] Biochemical remission was defined as a normal IGF-I level combined with a glucose-suppressed GH level of ≤ 0.4 ng/ml, or alternatively, combined with a basal GH level of ≤ 1 ng/ml. The IGF-I level was always evaluated according to age-adjusted diagrams.[16]

### *Statistical Evaluation*

Continuous variables are shown as the mean values ± the SEM and the range. Categorical values are shown as percentages. Continuous variables between patients with prolactinomas, acromegaly, or Cushing disease were analyzed by ANOVA, followed by a Tukey post hoc test. Tumor diameter between cured and noncured patients was assessed using a Mann-Whitney U-test. Binary logistic regression was used to determine the effect of extent of resection, tumor size, suprasellar extension, and invasion of the CS on endocrinological remission. A conditional backward stepwise method was used to calculate a multivariate logistic regression model. Preoperative and postoperative hormone levels in serum were assessed using a paired Student t-test. A p value $< 0.05$ was considered significant. Statistical analyses were performed using SPSS software (version 18.0 for Macintosh).

## Results

*Overall Patient Characteristics*

At total of 86 patients underwent resection of functional pituitary adenomas in which a purely endoscopic transsphenoidal technique was used. The cohort was composed of 37 male and 49 female patients with a mean age of 45.2 years (range 12–82 years; Table 1). Our series contains 35 patients with prolactinomas, 18 with Cushing disease, and 33 with GH-secreting adenomas. The majority of patients (85%) who underwent resection sought medical attention for symptoms related to excess hormone production. The remaining patients complained of severe headaches (4.7%), diplopia (3.5%), or vision loss (10.5%). Patients with diplopia and vision loss had significantly larger adenomas compared with the rest of the cohort (3.3 cm and 2.6 cm, respectively, vs 1.2 cm maximum tumor diameter; $p < 0.001$). In patients with loss of vision, visual field testing revealed bitemporal defects in 3 patients, binasal defects in 1 patient, or hemianopia in 2 patients. One-third of patients with acute vision loss where found to have pituitary apoplexy on MR imaging. The remaining 2 patients with apoplexy presented with acute onset of severe headaches. In our cohort, 20.9% of patients had undergone a previous resection. Preoperative MR imaging revealed macroadenomas (maximum diameter > 1 cm) in two-thirds of our patients. Invasion of the CS was present in 20.9%, and suprasellar tumor extension was detected in 29.1%. Whereas the pituitary–hypothalamic axis was intact in the majority of patients (89.5%), 6 patients were found to have hypogonadism, 2 had hypothyroidism, and 1 suffered from both panhypopituitarism and diabetes insipidus prior to surgery.

*Surgical Results*

Endoscopic endonasal transsphenoidal procedures lasted an average of 167.3 minutes (range 79–380 minutes). The mean estimated blood loss was 133.1 ml (range 20–900 ml) for all procedures in this cohort. Significant suprasellar tumor extension required an extended transsphenoidal approach in 5 patients (5.8%). Labeling of CSF by intrathecal fluorescein revealed intraoperative CSF leaks in 47% of procedures. As expected, adenomas with intraoperative CSF leaks had a significantly larger diameter compared with the remaining adenomas (1.9 cm vs 1.2 cm, $p < 0.01$). The skull base defect was closed in a multilayered fashion with vomer (28%), Porex (4%), fat (57%), fascia lata (4%), and DuraSeal (83%). A nasoseptal flap was used in 7 patients, the majority of whom had intraoperative CSF leaks. Moreover, tumors that required nasoseptal flaps had a significantly larger diameter than tumors in which no flap was used (2.5 cm vs 1.4 cm, $p < 0.05$). Postoperative imaging revealed a GTR in 75.6% of all patients in our cohort (Table 2). The rate of GTR was 90.6% for microadenomas and 66.7% for macroadenomas. Once functional adenomas had invaded the CS, the rate of GTR decreased to 33.3%. Thus, invasion of the CS was a significant negative predictor for GTR (OR

**TABLE 1: Characteristics in 86 patients with functional pituitary adenomas**

| | | Type of Pathology | | |
|---|---|---|---|---|
| Characteristic | Total | PRL-Secreting | ACTH-Secreting | GH-Secreting |
| no. of patients | 86 | 35 | 18 | 33 |
| sex | | | | |
| M | 37 (43.0%) | 13 (37.1%) | 5 (27.8%) | 19 (57.6%) |
| F | 49 (57.0%) | 22 (62.9%) | 13 (72.2%) | 14 (42.4%) |
| mean age in yrs (± SEM) | 45.2 ± 1.8 | 36.3 ± 2.5* | 53.8 ± 3.8 | 49.9 ± 2.6 |
| previous op | | | | |
| yes | 18 (20.9%) | 8 (22.9%) | 6 (33.3%) | 4 (12.1%) |
| no | 68 (79.1%) | 27 (77.1%) | 12 (66.6%) | 29 (87.9%) |
| max tumor diameter | | | | |
| <1 cm | 32 (37.2%) | 13 (37.1%) | 11 (61.1%) | 8 (24.2%) |
| >1 cm | 54 (62.8%) | 22 (62.9%) | 7 (38.9%) | 25 (75.8%) |
| invasion of CS | | | | |
| yes | 18 (20.9%) | 5 (14.3%) | 3 (16.7%) | 10 (30.3%) |
| no | 68 (79.1%) | 30 (85.7%) | 15 (83.3%) | 23 (69.7%) |
| suprasellar extension | | | | |
| yes | 25 (29.1%) | 14 (40.0%) | 3 (16.7%) | 8 (24.2%) |
| no | 61 (70.9%) | 21 (60.0%) | 15 (83.3%) | 25 (75.8%) |
| apoplexy | | | | |
| yes | 5 (5.8%) | 5 (14.3%) | 0 (0.0%) | 0 (0.0%) |
| no | 81 (94.2%) | 30 (85.7%) | 18 (100.0%) | 33 (100.0%) |

* Significant according to ANOVA ($p < 0.001$) and the Tukey post hoc test ($p < 0.01$) compared to GH-secreting lesions; $p < 0.001$ compared to ACTH-secreting adenomas.

**TABLE 2: Outcome in 86 patients with functional pituitary adenomas***

| Characteristic | Total | Type of Pathology | | |
|---|---|---|---|---|
| | | PRL-Secreting | ACTH-Secreting | GH-Secreting |
| no. of patients | 86 | 35 | 18 | 33 |
| GTR | | | | |
| yes | 65 (75.6%) | 26 (74.3%) | 13 (72.2%) | 26 (78.8%) |
| no | 21 (24.4%) | 9 (25.7%) | 5 (27.8%) | 7 (21.2%) |
| EC | 85† | | | |
| yes | 51 (60.0%) | 24 (70.6%) | 11 (61.1%) | 16 (48.5%) |
| no | 34 (40.0%) | 10 (29.4%) | 7 (38.9%) | 17 (51.5%) |
| EC in microadenomas | 32 | | | |
| yes | 24 (75.0%) | 12 (92.3%) | 6 (54.5%) | 6 (75.0%) |
| no | 8 (25.0%) | 1 (7.7%) | 5 (45.5%) | 2 (25.0%) |
| EC in macroadenomas | 53 | | | |
| yes | 27 (50.9%) | 12 (57.1%) | 5 (71.4%) | 10 (40%) |
| no | 26 (49.1%) | 9 (42.9%) | 2 (28.6%) | 15 (60.0%) |
| EC in adenomas w/ CS invasion | 18 | | | |
| yes | 7 (38.9%) | 3 (60.0%) | 1 (33.3%) | 3 (30.0%) |
| no | 11 (61.1%) | 2 (40.0%) | 2 (66.7%) | 7 (70.0%) |
| GKS | | | | |
| yes | 12 (14.0%) | 3 (8.6%) | 4 (22.2%) | 5 (15.2%) |
| no | 74 (86.0%) | 32 (91.4%) | 14 (77.8%) | 28 (84.8%) |
| mean time of last FU in mos (± SEM) | 22.8 ± 2.2 | 22.3 ± 3.4 | 24.8 ± 5.1 | 22.2 ± 3.9 |

* EC = endocrinological cure; FU = follow-up.
† One patient was lost to endocrinological follow-up.

0.076, $p < 0.001$; 95% CI 0.023–0.255), whereas tumor diameter and suprasellar extension were not predictors of extent of resection. The average hospital stay was 4.3 days (range 2–32 days). The average length of the follow-up period from resection to laboratory testing was 22.8 months (range 1–76 months; Table 2).

*Prolactinomas*. In the current series, 35 patients with PRL-secreting adenomas underwent an endoscopic transsphenoidal tumor resection (Table 1). The mean age of this group was 36.3 years (range 12–73 years), and it was composed of 22 female and 13 male patients. Those with prolactinomas were significantly younger compared with patients with GH- or ACTH-secreting adenomas ($p < 0.001$). The majority (80%) of these patients had attempted medical therapy to control excess PRL secretion. Medical therapy failed for 3 main reasons: 1) insufficient control of excess hormone secretion (12 patients); 2) enlargement of the pituitary adenoma despite maximum medical therapy (5 patients); and 3) intolerable adverse medication effects (11 patients). Seven patients with PRL-secreting adenomas underwent resection without a trial of medical therapy. Five of these patients presented with acute vision loss, and 2 presented with severe headaches, of which apoplexy was the cause in 5 patients. All adenomas complicated by apoplexy were prolactinomas. Analysis of preoperative imaging revealed an average maximum diameter of 1.5 cm (range 0.4–4 cm). Thus, 62.9% of prolactinomas were classified as macroadenomas. Endoscopic endonasal transsphenoidal surgery resulted in a GTR in 74.3% of patients with PRL-secreting adenomas (Table 2). Similarly, 70.6% of patients with prolactinomas achieved endocrinological remission. Of the 24 cured patients, 1 required additional GKS. Resection led to a significant reduction of immediate postoperative ($p < 0.05$) and last follow-up ($p < 0.001$; Table 3) serum PRL levels compared with preoperative levels. Of 29 patients with prolactinomas who had an intact pituitary–hypothalamic

**TABLE 3: Endocrinological outcome in 86 patients with functional pituitary adenomas**

| Outcome | Hormone Level | | | | |
|---|---|---|---|---|---|
| | PRL (ng/ml) | ACTH (pg/ml) | Cortisol (mg/ml) | GH (ng/ml) | IGF-I (ng/ml) |
| excess serum hormone levels | | | | | |
| preop | 684.9 ± 308.4 | 85.4 ± 19.1 | 16.5 ± 4.2 | 30.3 ± 8.2 | 833.5 ± 56.5 |
| postop | 107.9 ± 50.1 | 42.0 ± 18.2 | 13.6 ± 4.3 | 3.9 ± 1.2 | 469.7 ± 42.5 |
| at last FU | 34.1 ± 11.8 | 45.0 ± 14.4 | 9.8 ± 2.0 | 2.3 ± 0.9 | 295.6 ± 40.1 |

axis preoperatively, 24 remained intact. Two patients developed new hypothyroidism, 2 had hypogonadism, and 1 had diabetes insipidus.

*Cushing Disease*. Our cohort included 18 patients in whom Cushing disease was diagnosed based on endocrinological and clinical evaluation (Table 1). Patients with Cushing disease were on average 53.8 years old (range 25–82 years). There were 13 female and 5 male patients. The gross majority of patients (72.2%) with ACTH-producing adenomas presented with classic cushingoid symptoms. Two patients received the diagnosis of Cushing disease during the workup for intractable hypertension, and 1 patient during the workup for diplopia. Analysis of preoperative imaging revealed an average maximum tumor diameter of 0.8 cm (range 0–2.3 cm). The ACTH-secreting adenomas were significantly smaller compared with both PRL- ($p < 0.05$) and GH-secreting ($p < 0.01$) adenomas. Thus, only 38.9% of ACTH-secreting adenomas were classified as macroadenomas. No distinguishable pituitary pathological features could be identified on preoperative MR imaging in 4 patients. These patients underwent exploration of the pituitary gland without further prior workup, and endocrinological remission was achieved in 2 of these 4 patients. Two patients did not achieve biochemical remission according to our criteria. One of them has ACTH and serum cortisol levels that remain consistently within normal limits 33 months after the procedure, whereas the other patient had good relief of his symptoms for 6 years, but eventually suffered from a recurrence requiring repeat resection, resulting again in alleviation of his excess cortisol production. Endoscopic endonasal transsphenoidal surgery resulted in GTR in 72.2% of patients with Cushing disease (Table 2). However, only 61.1% of patients achieved endocrinological cure. Biochemical remission rates were 50% in patients with lesions that were not visible on preoperative imaging, 54.5% in all microadenomas, and 71.4% in macroadenomas. Of 11 patients with ACTH-secreting adenomas that were cured, 2 underwent GKS. Endoscopic endonasal transsphenoidal resection led to a significant reduction of postoperative ACTH levels in serum compared with preoperative serum levels ($p < 0.05$; Table 3). Of 16 patients with Cushing disease who had an intact pituitary–hypothalamic axis preoperatively, 4 developed defects in one axis.

*Growth Hormone–Producing Adenomas*. A total of 33 patients suffered from excess GH secretion (Table 1). This cohort consisted of 14 female and 19 male patients, and the average age was 49.9 years (range 20–77 years). Two-thirds of patients with GH-producing adenomas presented with classic acromegalic symptoms. Four GH-secreting adenomas were diagnosed incidentally, 2 patients sought medical attention for headaches, and 1 patient each sought help for complaints of bone pain, joint pain, diplopia, amenorrhea, or sleep apnea. Evaluation of GH-secreting adenomas on preoperative MR imaging revealed an average maximum diameter of 1.7 cm (range 0.6–4 cm). Thus, 75.8% of patients with acromegaly had macroadenomas, and 30.3% of GH-secreting adenomas had invaded the CS. A GTR was achieved in 78.8% of patients, and 48.5% fulfilled criteria for endocrinological cure (Table 2). Biochemical cure was achieved in 75% of GH-secreting microadenomas, whereas the rate was lower in macroadenomas (40%) due to a high proportion of tumors with invasion of the CS. Of 17 patients who achieved endocrinological remission, 2 underwent GKS. Endoscopic endonasal transsphenoidal resection led to a significant reduction of GH levels in serum immediately postoperatively ($p < 0.01$) as well as at last follow-up ($p < 0.05$) compared with preoperative levels (Table 3). A significant reduction of serum levels of IGF-I was also observed postoperatively ($p < 0.001$) as well as at the last follow-up ($p < 0.001$) compared with preoperative serum levels. Of 32 patients with GH-secreting adenomas who had an intact pituitary–hypothalamic axis preoperatively, 2 suffered from panhypopituitarism and 2 from hypogonadism following endoscopic endonasal transsphenoidal resection.

### *Predictors for Endocrinological Remission*

Adenomas allowing for endocrinological remission had a significantly smaller diameter compared with lesions that were not cured (1.2 cm vs 1.8 cm, respectively; $p < 0.05$; Fig. 1). Accordingly, univariate logistic regression identified GTR, a maximum adenoma diameter of < 1 cm, lack of suprasellar extension, and lack of CS in-

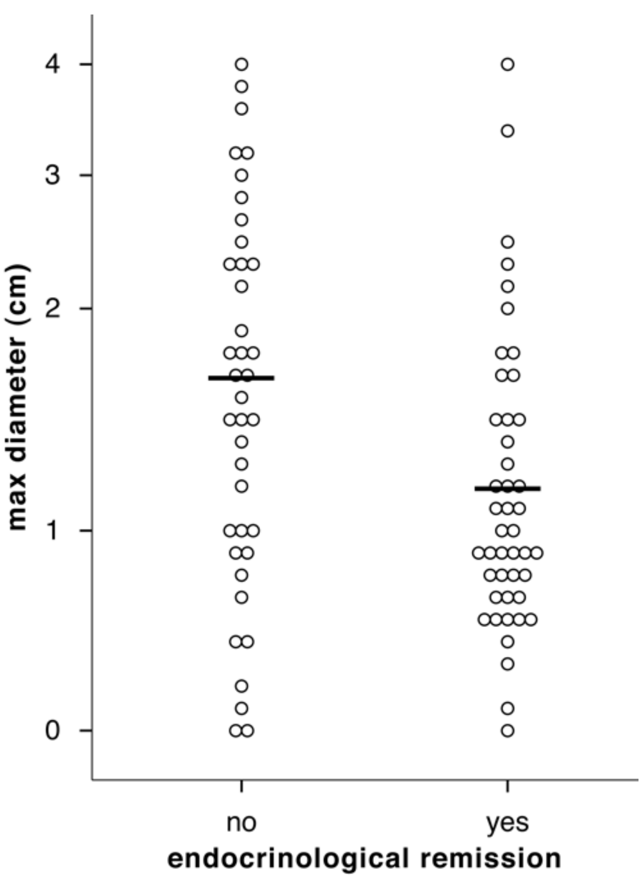


**Fig. 1.** Graph showing association of tumor size with endocrinological remission. Adenomas that allow for biochemical cure by endoscopic transsphenoidal resection have a significantly smaller maximum diameter on univariate analysis compared with the remaining adenomas ($p < 0.05$). *Horizontal bars* indicate the mean values.

TABLE 4: Predictors for endocrinological cure in 86 patients with functional pituitary adenomas*

| | Univariate Analysis | | | Multivariate Analysis | | |
|---|---|---|---|---|---|---|
| Adenoma Characteristics | OR | p Value | 95% CI | OR | p Value | 95% CI |
| GTR | 4.40 | 0.006 | 1.54–12.57 | 3.95 | 0.013 | 1.344–11.63 |
| no suprasellar extension | 3.23 | 0.017 | 1.23–8.52 | 2.86 | 0.042 | 1.040–7.856 |
| microadenoma | 2.89 | 0.031 | 1.10–7.58 | | NS | |
| no CS invasion | 3.01 | 0.044 | 1.03–8.80 | | NS | |

* NS = not significant.

vasion as positive predictors for endocrinological cure (Table 4). When combining these significant predictors in a multivariate analysis, only GTR and suprasellar tumor extension remained significant independent predictors for biochemical remission.

*Postoperative Complications*

There was no operative or perioperative death in this cohort. There was 1 case of meningitis leading to hydrocephalus requiring a shunt (Table 5). Two patients developed postoperative CSF leaks, which were treated with 4 days of CSF diversion via lumbar drainage. Two patients developed sinusitis after the surgery. One patient complained of a unilateral dry eye requiring treatment with artificial tears.

## Discussion

In this series of patients, we present endocrinological outcome according to the most recent updated criteria for endocrinological cure following a purely endoscopic endonasal transsphenoidal surgery for functional pituitary adenomas. The criteria for endocrinological cure have evolved over the last decades, and until now there has been little universal consensus. The use of different criteria makes comparisons of endocrinological outcomes between different surgical series difficult. For the current series we used the latest consensus criteria for diagnosis of postoperative endocrinological remission for acromegaly, Cushing disease, and prolactinomas.[3,9,16] Because the endoscopic technique constitutes the latest refinement of transsphenoidal surgery,[40] a comparison of our results with a standard microscopic transsphenoidal technique was performed.

In our series endocrinological cure was achieved for 70.6% of PRL-secreting adenomas. This is similar to the weighted average cure rate (62%) derived from several microscopic series.[29,33,39,43] It is obvious that the value of this comparison is limited due to heterogeneities of adenoma size and invasiveness, follow-up times, and definition of endocrinological cure. However, it further corroborates previous claims of equal efficiency of endoscopic technique for achieving biochemical cure in PRL-secreting adenomas.[12,14] In a study of endoscopic transsphenoidal surgery by Dehdashti and colleagues,[12] the same criteria for endocrinological cure for PRL-secreting adenomas were used as in the current series (Table 6). However, adenoma characteristics are quite different. In the current series, 8.6% of PRL-secreting adenomas required an extended approach for appropriate access to suprasellar portions, whereas adenomas that required extended approaches were excluded by Dehdashti et al. Moreover, the rate of CS invasion was higher in the current series (14.3%) compared with the aforementioned study (8%). This may explain the slightly higher biochemical cure rate (88%) reported by Dehdashti and colleagues for their 25 prolactinomas. The second published series reporting endocrinological outcome following endoscopic transsphenoidal adenoma resection has a patient cohort that appears to be more similar to ours.[14] Despite endocrinological criteria that were not as stringent as in our series (maximum serum PRL level for female patients was 30 ng/ml, compared with 20 ng/ml in the current series), the cure rate for Frank and colleagues[14] (75.7%) is similar to the rate achieved in our series. Endoscopic transsphenoidal resection yielded endocrinological cure rates above 85% for PRL-secreting microadenomas in both studies[12,14] as well as in the current series. Endocrinological remission rates for PRL-secreting adenomas with invasion of CS differ among the series. Whereas Frank and colleagues report a cure rate (36.5%) that is comparable to the current series (60.0%), Dehdashti and colleagues do not report cures in patients with this type of lesion.

For ACTH-secreting adenomas an average cure rate of

TABLE 5: Complications in 86 patients with functional pituitary adenomas

| Type of Complication | No. of Patients (%) | Treatment |
|---|---|---|
| meningitis & communicating hydrocephalus | 1 (1.2) | antibiotics & ventriculoperitoneal shunt |
| CSF leak | 2 (2.3) | lumbar CSF diversion |
| panhypopituitarism* | 2 (2.3) | hormone replacement |
| sinusitis | 2 (2.3) | antibiotics |
| dry eye | 1 (1.2) | artificial tears |

* In patients with intact pituitary–hypothalamic axis preoperatively.

**TABLE 6: Literature review of endocrinological remission following transsphenoidal surgery***

| | PRL-Secreting | | | ACTH-Secreting | | | GH-Secreting | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Authors & Year | No. of Pts | GTR | EC | No. of Pts | GTR | EC | No. of Pts | GTR | EC | FU (mos) |
| Frank et al., 2006 | 66 | NA | 75.7% | 56 | NA | 67.8% | 83 | NA | 69.0% | 54.0 |
| Dehdashti et al., 2008 | 25 | 92.0% | 88.0% | 27 | 85.0% | 81.0% | 34 | 85.0% | 71.0% | 19.0 |
| present study | 35 | 74.3% | 70.6% | 18 | 72.2% | 61.1% | 33 | 78.8% | 48.5% | 22.8 |

* NA = not available; Pts = patients.

78% is reported in the major microscopic series.[4,7,17,21,41,46] In our series endocrinological remission was achieved in 61.1% of patients. A low rate of cure (50%) was detected in adenomas that were obscure on preoperative imaging. Moreover, endocrinological cure was achieved in only 40% of patients with visible adenomas of < 5-mm diameter on preoperative MR imaging, whereas endocrinological cure was obtained in 100% of microadenomas > 5 mm. Poor preoperative visualization of ACTH-secreting adenomas is a well-documented poor prognostic factor for endocrinological remission.[6] Accordingly, we detected lower cure rates in ACTH-secreting microadenomas compared with those reported in studies by Frank et al.[14] and Dehdashti et al.[12] (54.5%, 67.7%, and 100%, respectively), whereas the cure rates for macroadenomas were comparable (71.4%, 62.5%, and 68%, respectively).

The current literature on microscopic transsphenoidal resection of GH-secreting adenomas suggests an average cure rate of approximately 67%.[1,15,23,31,44,45] In the current study endocrinological remission was achieved in only 51.5% of GH-secreting adenomas. The rate of biochemical cure for GH-secreting microadenomas was 75% in the current series, and thus was similar to the rates reported by Frank and colleagues[14] (83%) as well as by Dehdashti and colleagues[12] (83%). Given the large proportion of GH-secreting macroadenomas that had invaded the CS, it is not surprising that we detected lower cure rates in GH-secreting macroadenomas compared with studies by Frank et al. and Dehdashti et al. (40%, 64.5%, and 70.1%, respectively).

The current patient cohort includes a great proportion of adenomas with invasion of the CS (20.9%). Using a microsurgical transsphenoidal approach, Kitano and colleagues[22] report a 67% rate of endocrinological remission in 12 patients with GH-secreting pituitary adenomas invading the CS. Kitano and colleagues used a microscopic endoscope-assisted transsphenoidal technique to reach tumors that had invaded the CS. The mean blood loss was approximately 1000 ml, compared with approximately 132 ml for tumors with CS invasion in our current cohort. Kitano and colleagues report a 26% rate of transient extraocular palsy, whereas this complication did not occur in the current series. The aggressiveness used to achieve resection of intracavernous tumor varies in the endoscopic literature. Whereas in one recent endoscopic series the investigators did not attempt resection of tumor from the CS,[12] Frank and Pasquini[13] report endocrinological remission in 43% of functional tumors with invasion of the CS resected using the endoscopic technique. A similar rate of cure was achieved in the current series (38.9%). It is our opinion that one must balance risk with benefit when operating in the CS, and it may be preferable to control residual tumor with stereotactic radiosurgery rather than to achieve GTR associated with a risk morbidity.

A potential limitation of the current study is the relatively short follow-up time of 22.8 months. The occurrence of late recurrences following resection of functioning adenomas in patients with assumed endocrinological cure is well established.[2,17,42,46] These recurrences have been the main motivation to introduce more and more stringent criteria for endocrinological cure. Early results from recent endoscopic series[12,14] as well as the current study, in which no recurrences were observed in patients who achieved endocrinological remission, are encouraging. However, continued monitoring of these patient cohorts is required to eventually provide long-term endocrinological remission rates following endoscopic resection of functional pituitary adenomas.

## Conclusions

An endoscopic transsphenoidal resection of functional pituitary adenomas leads to endocrinological remission in 60% of patients. Importantly, our treatment regimen of endoscopic resection in combination with GKS for possible residual disease allows for endocrinological remission in a significant proportion of functional adenomas with CS invasion as well as in recurrent adenomas, while minimizing procedure-related morbidity.

### Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Schwartz, Hofstetter. Acquisition of data: Hofstetter, Shin, Mubita. Analysis and interpretation of data: Schwartz, Hofstetter. Drafting the article: Hofstetter, Shin. Critically revising the article: Schwartz, Huang, Boockvar, Anand. Reviewed final version of the manuscript and approved it for submission: Schwartz. Statistical analysis: Hofstetter.

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# Evidence of improved surgical outcome following endoscopy for nonfunctioning pituitary adenoma removal

## Personal experience and review of the literature

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*Object.* Because of their size and lateral extension, total removal of nonfunctioning pituitary adenomas (NFPAs) remains a challenge and postoperative tumor remnants are frequent. Endoscopy has improved the surgeon's view; however, its superiority in terms of surgical outcome remains undetermined. The authors' aim in this study was to compare the clinical results and morbidity between microscopic and endoscopic techniques in 164 patients with NFPAs.

*Methods.* Tumoral (3D MR imaging), endocrinological, and ophthalmological results and morbidity were compared between 2 groups of 82 patients with newly diagnosed NFPAs surgically treated via either a sublabial microscopic approach (Group B) or a fully endonasal endoscopic technique (Group A).

*Results.* The groups showed no difference in terms of clinical features, tumor size, or cavernous sinus invasion ($p > 0.05$). One year postoperatively, the quality of resection was significantly improved in Group A (gross-total removal [GTR]: 74% vs 50% in Group B, $p = 0.002$) with greater control of lateral extension (Knosp Grade 2: GTR 88.2% vs 47.8% in Group B, $p = 0.02$; Knosp Grade 3: 67.9% vs 16.7% in Group B, $p < 0.001$) and suprasellar extension (tumor height 20–30 mm: GTR 76% vs 53% in Group B, $p = 0.01$). Endocrinological outcome in patients with a partial deficiency in anterior pituitary function preoperatively was significantly better in Group A (improvement 56% vs 25% in Group B, stabilization 22% vs 46%, and aggravation 22% vs 29%; $p = 0.01$). Among the ophthalmologically symptomatic patients, 100% from Group A improved compared with 93% in Group B ($p = 0.35$). Lastly, no significant difference was found regarding morbidity. These data were supported by the literature in which the GTR rate is consistently higher for endoscopy compared with microscopy.

*Conclusions.* In this large series of patients with NFPAs, endoscopy improved the quality of resection and endocrinological outcome. Larger studies focusing on the impact of these promising results on the long-term recurrence of NFPAs are warranted. *(DOI: 10.3171/2011.1.FOCUS10308)*

**Key Words** • **endoscopy** • **minimally invasive surgery** • **nonfunctioning pituitary adenoma** • **transsphenoidal surgery**

Since the introduction of operative microscopy and intraoperative fluoroscopy by Guiot et al.[16] and Hardy[18] in the 1960s, microsurgery via a transsphenoidal approach became the gold standard for pituitary surgery, representing the technique of choice for about 99% of pituitary adenomas. Sublabial and endonasal approaches are commonly used, with increasing interest in the latter less aggressive to nasal structures. Although the results of microsurgery for pituitary disease appear good for both macroadenomas and microadenomas, there is still room for improvement, especially with regards to the lateral and upper fields of vision. Introduced in the

*Abbreviations used in this paper:* ACTH = adrenocorticotropic hormone; FSH = follicle-stimulating hormone; GH = growth hormone; GTR = gross-total resection; ICA = internal carotid artery; LH = luteinizing hormone; NFPA = nonfunctioning pituitary adenoma; PRL = prolactin; TSH = thyroid-stimulating hormone.

1990s,[21] endoscopy marked an important milestone for pituitary or skull base surgery and was widely promoted in particular by Cappabianca et al.[2] and Jho and Carrau.[7,25–27] While the endoscopic endonasal approach is becoming the technique of choice for pituitary surgery,[4,8,10] improvements with regard to surgical outcome remain undetermined.

Immunonegative, gonadotropic, and silent adenomas are grouped under the name of NFPA since they have no specific clinical symptoms.[1] Often diagnosed late as macroadenomas, they remain a challenge to neurosurgeons given the frequent occurrence of residual tumor postoperatively. Since endoscopy permits better visualization of the operative site, we predicted that this approach would in turn permit better resection. To test this hypothesis, we compared our data for 164 NFPAs from 2 consecutive series surgically treated by the same surgeons—82 via the microscopic approach and 82 via a fully endoscopic approach—and reviewed the literature available on this topic.

## Methods

### *Study Population*

*Inclusion Criteria.* Between 2006 and 2009, 350 patients bearing pituitary adenomas underwent consecutive surgical treatment via a purely endonasal endoscopic approach by the same senior surgeon (E.J.) in our department. Newly diagnosed NFPAs were found in 82 of the patients (Group A). To assess endoscopic versus microscopic surgical techniques we compared Group A with the last 82 consecutive patients with newly diagnosed NFPAs treated in the preceding year via a sublabial microsurgical approach (Group B) undertaken by the same senior pituitary surgeon (E.J., > 300 patients treated microscopically) or another expert pituitary surgeon (G.P., > 1000 patients treated microscopically).

*Exclusion Criteria.* Patients previously treated with surgery or radiation, younger than 18 years of age, or with < 6 months of follow-up at the time of the study were excluded from the analysis.

### *Surgical Procedure*

*Group A: Endoscopic Approach.* Patients in Group A underwent pure endonasal endoscopic transsphenoidal surgery with a 4-mm rigid endoscope (Karl Storz) and an intraoperative MR imaging neuronavigation system (Medtronic) as previously described.[5,23] Briefly, which side of the nasal cavity to use was determined by the nasal anatomy (septal deviation and megaturbinate), lateral extension (contralateral approach to a lateral extension), and size of the tumor (bilateral for large tumors). A unilateral approach was used in most cases, except for large tumors. The entire endonasal procedure until the opening of the sellar floor was performed with a hand-held, short 0° endoscope (4 mm, 18 cm). The superior and middle turbinates were identified and gently pushed aside laterally. Mucosa from the sphenoidal ostium to the choana at the base of the vomer was coagulated and thereafter opened up, pushing away the vomer until the contralateral ostium appeared. A large sphenoidotomy was performed, and the bone of the sella turcica was removed from one cavernous sinus to the other and from the anterior skull base to the clivus. After opening the dura mater, a long 0° endoscope (4 mm, 24 cm) fixed on a table-mounted endoscope holder was introduced into the nostril allowing both hands for tumor dissection and removal. Adenomas were removed using a piecemeal technique similar to that applied in microscopic surgery. At the end of the procedure, the sellar and suprasellar regions were explored using 0°, 30°, and rarely 45° endoscopes pushed up through the sella turcica. At the end of the procedure, jugular compression was applied to detect any CSF fistula before closing. The closure technique did not differ from the one used during microscopic surgery; bioabsorbable dura mater was placed in the extradural plane with fibrin glue if no CSF leakage occurred and we used autologous material such as fat or fascia lata with fibrin glue and CSF lumbar drainage or puncture in the event of a fistula. No nasal packing was used with the endoscopic technique.

*Group B: Microscopic Approach.* Patients in Group B underwent the traditional sublabial transeptal transsphenoidal surgery described by Guiot et al. in 1959[16] and Hardy[18] in 1969. Briefly, a short incision was made in the superior gingival sulcus, and the cartilaginous septum was pushed away to the left, allowing placement of a nasal speculum. The sphenoid was opened up and the speculum was pushed inside. Under microscopic visualization, sellar opening, tumor removal, and sellar closure techniques were performed as described above for the endoscopic technique. At the end of the surgery, the mucosa was closed with absorbable sutures, and bilateral nasal packing was placed in each nostril for 24 hours.

### *Neuroimaging Evaluation*

Before surgery, the imaging protocol included systematic 3D T1-weighted sequences with and without contrast injection and a 3D T2 sequence, plus an additional neuronavigation sequence using 1.5-T MR imaging (Siemens) for Group A. Tumor volume (height × length × width), tumor height, and cavernous sinus invasion were defined using coronal T2 and 3D T1-weighted MR imaging with and without contrast injection, with a special note for the latter 2 parameters considered as important factors determining surgical failure.[14] For cavernous sinus invasion, the Knosp classification was used.[31] According to Knosp et al.,[31] Grade 0–1 tumors are considered noninvasive to the cavernous sinus (do not cross the cross-sectional centers of the intra- and supracavernous ICA); most Grade 2 lesions (extending beyond the intercarotid line but not beyond or tangent to the lateral aspects of the intra- and supracavernous ICA) and Grade 3 tumors (extending beyond the tangent on the lateral aspects of the intra- and supracavernous ICA) are considered invasive; and Grade 4 lesions (surrounding the ICA) clearly invade the cavernous sinus. If the grading was different between the 2 cavernous sinuses for any patient, the tumor was classified according to the higher grade. In 1 case in which MR imaging was not feasible for health reasons (pacemaker), a CT scan with 3D reconstruction was obtained.

At 3, 6, and 12 months following surgery and once per year thereafter, all patients surgically treated for pituitary adenomas at our center underwent postoperative control MR imaging with the same sequences as those performed preoperatively (except for neuronavigation). As the goal of this study was to evaluate the quality of tumor removal with respect to the technique applied, we used the 12-month postoperative MR imaging study for analysis to avoid any artifacts. The quality of resection, as judged by the 2 senior pituitary surgeons (E.J. and G.P.) and an independent neuroradiologist (V.L.), was classified as total or subtotal (classified as subtotal in cases of doubt). Any remaining residue was classified in terms of its location (suprasellar, parasellar, or intracavernous) and eventually its compressive effect on the optic chiasma.

*Endocrinological Evaluation*

Before and after surgery, all patients were assessed with static and dynamic endocrinological tests to globally evaluate anterior pituitary function.

After surgery, patients' conditions were classified as having improved or worsened when one sector of pituitary function had been recovered or lost, respectively, and stable if no change had occurred. Each patient returned to the clinic for examination and tests. All results were considered at 12 months.

Postoperative transitory or definitive diabetes insipidus was classified in morbidity.

*Ophthalmological Examination*

Before and after surgery, patients underwent a complete ophthalmological examination of visual acuity, visual field, and eye fundus. Visual acuity was considered normal at 20/10. Visual field was tested with an automated perimeter. A mean deviation of 1 dB for the affected eye was considered significant.

In comparing the postoperative and preoperative results, we classified a patient's condition as normal if all parameters normalized, improved if 1 of the parameters improved, stable if there was no change, and worsened in any other situation. All results were considered at the time of the 12-month follow-up.

*Pathological Diagnosis*

Fragments of all tumors were fixed in Bouin fixative and processed normally for paraffin embedding. Five-micrometer-thick sections were stained with Herlant tetrachrome and PAS Orange, and immunocytochemistry was performed according to the avidin-biotin-peroxidase method for PRL, GH, ACTH, FSH, LH, TSH, and α-subunit for glycoproteins. The following antibodies were used: monoclonal anti-PRL (1:400, Immunotech), polyclonal anti-GH (1:15000, NIDDK), polyclonal anti-ACTH (1:20,000, gift of MP Dubois), monoclonal anti-βFSH (1:6000, Immunotech), polyclonal anti-βLH (1:8000, NIDDK), monoclonal anti-βTSH (1:150, Immunotech), and monoclonal anti–α–subunit (1:150, Immunotech). Tumors were classified via immunocytochemistry according to the WHO classification.[32] They were considered immunonegative when no hormone was detected. Tumors immunopositive for one hormone without clinical or biological signs were classified as silent adenomas.

*Statistical Analysis*

The quality of microscopic and endoscopic removal was compared using a Fisher exact test. Initial characteristics of the 2 groups were compared using a Fisher exact test for qualitative variables or a Student t-test for quantitative variables. Items were considered statistically significant if the probability value was $< 0.05$. Statistical analyses were computed using the SAS software, version 9.1.3 (SAS, Inc.).

## Results

*Study Population*

The general characteristics of the 2 groups of patients are summarized in Table 1. Except for histological parameters, with fewer silent and immunonegative adenomas in Group B as compared with Group A, no statistical difference was observed between the 2 groups, particularly with regard to tumor volume, tumor height, and cavernous sinus invasion.

*Quality of Removal*

Whichever technique was used, the goal of surgery was to achieve GTR.

*Considering the Whole Population*. As confirmed on postoperative MR imaging, GTR was achieved in 61 (74%) of 82 patients in Group A compared with 41 (50%) of 82 patients in Group B ($p = 0.002$; Table 2). Postoperatively, 5 cases of noncompressing suprasellar remnants were noticed in Group A, whereas among the 10 cases of suprasellar remnants in the Group B, 3 were found to compress the optic chiasm and required additional surgery. No intrasellar tumor remnant was found in Group A, compared with 11 cases in Group B.

*According to Tumor Height*. In Group A, the mean tumor height was 25.91 mm (range 10–50 mm; Fig. 1 and Table 1). Gross-total resection was achieved in 94% of cases in which the tumor was < 20 mm, in 76% for lesions between 20 and 30 mm, and in 53% for lesions > 30 mm.

In Group B, the mean height of the tumors was 26.3 mm (range 12–46 mm). Gross-total resection was achieved in 73% of cases in which the tumor height was < 20 mm, in 53% for those between 20 and 30 mm, and in 19% for those > 30 mm. The superiority of endoscopy was significant when considering tumors between 20 and 30 mm ($p = 0.02$) and tended toward significance for tumors > 30 mm ($p = 0.07$).

*According to Lateral Extension*. Grade 0 or 1 noninvasive tumors were completely removed in > 90% of cases in both patient groups (Fig. 2). Concerning the Grade 2 and 3 tumors, in most cases considered as invasive, the endoscopic technique was significantly better at controlling and removing the lateral extension, with GTR

**TABLE 1: Summary of characteristics in 164 patients with NFPAs***

| Parameter | Endoscopic Op | Microscopic Op | p Value |
|---|---|---|---|
| total no. of patients | 82 | 82 | |
| age in yrs | | | 0.94† |
| median | 57.00 | 56.50 | |
| range | 20–82 | 27–84 | |
| M/F ratio | 47:35 | 51:31 | 0.52 |
| symptoms on presentation (%) | | | 0.75‡ |
| visual deficit | 34 (41.5) | 42 (51.2) | |
| headache | 12 (14.6) | 8 (9.8) | |
| endocrinological disorders | 16 (19.5) | 15 (18.3) | |
| apoplexy | 7 (8.5) | 6 (7.3) | |
| incidental finding | 13 (15.9) | 11 (13.4) | |
| clinical examination (%) | | | 0.88‡ |
| ophthalmology | | | |
| normal | 25 (30.5) | 20 (24.4) | |
| decrease in VA | 1 (1.2) | 1 (1.2) | |
| abnormal VF | 10 (12.2) | 13 (15.9) | |
| abnormal VA & VF | 42 (51.2) | 41 (50.0) | |
| palsy of CN | 2 (2.4) | 4 (4.9) | |
| abnormal VA & VF & CN palsy | 2 (2.4) | 3 (3.7) | |
| endocrinology | | | 0.36‡ |
| normal | 37 (45.1) | 31 (37.8) | |
| partial ant pituitary deficit | 32 (39.0) | 41 (50.0) | |
| total ant pituitary deficit | 13 (15.9) | 10 (12.2) | |
| preop MRI | | | |
| tumor vol in mm$^3$ | 13,190 | 14,506 | 0.46† |
| mean tumor height in mm (range) | 25.91 (10–50) | 26.3 (12–46) | 0.76† |
| <20 mm | 17 (20.7) | 15 (18.3) | |
| 20–30 mm | 46 (56.1) | 51 (62.2) | |
| >30 mm | 19 (23.2) | 16 (19.5) | |
| Knosp classification (%) | | | 0.74‡ |
| Grade 0/1 | 30 (36.6) | 28 (34.1) | |
| Grade 2 | 17 (20.7) | 23 (28) | |
| Grade 3 | 28 (34.1) | 24 (29.3) | |
| Grade 4 | 7 (8.5) | 7 (8.5) | |
| histology (%) | | | 0.02‡ |
| immunonegative adenoma | 24 (29.3) | 10 (12.2) | |
| FSH/LH adenoma | 48 (58.5) | 65 (79.3) | |
| silent adenoma | | | |
| ACTH | 4 (4.9) | 2 (2.4) | |
| GH | 2 (2.4) | 4 (4.9) | |
| PRL | 2 (2.4) | 1 (1.2) | |
| TSH | 2 (2.4) | 0 | |

* ant = anterior; CN = cranial nerve; VA = visual acuity; VF = visual field.
† Student t-test.
‡ Fisher exact test.

**TABLE 2: Tumor removal in the entire study population***

| Parameter | Endoscopic Op | Microscopic Op | p Value |
|---|---|---|---|
| GTR (%) | 61 (74) | 41 (50) | 0.002 |
| STR (%) | 21 (26) | 41 (50) | |
| tumor remnant location | | | 0.02 |
| cavernous sinus | 16 | 20 | |
| suprasellar (compressive) | 5 (0) | 10 (3) | |
| intrasellar | 0 | 11 | |

* STR = subtotal resection.

achieved in 88% and 67.9% of respective cases versus only 47.8% (p = 0.02) and 16.7% (p < 0.001) using the microscopic technique. Lastly, none of the Grade 4 tumors were completely removed.

*Ophthalmic Postoperative Status*

There was no significant difference in postoperative ophthalmic status between the 2 patient groups (Table 3). Among the entire series, none of the patients with normal preoperative examination results worsened. One hundred percent of the patients treated using the endoscopic technique improved (allowing a normal personal and professional life) or normalized compared with 93% in Group B (p = 0.35). Three patients in Group B did not recover and 1 worsened due to a postoperative suprasellar tumor remnant with hematoma requiring a second intracranial surgical intervention.

*Endocrinological Postoperative Outcome*

When anterior pituitary function was normal before surgery, 29% of patients in Group B compared with only 13.5% of those in Group A worsened postoperatively, although this difference was not significant (p = 0.14; Table 4).

Pituitary deficiency is a frequent feature associated with NFPAs. For patients suffering a partial pituitary deficiency, endoscopy allowed a total or partial recovery in 56% of patients in Group A compared with only 25% in Group B (p = 0.01). The entire pituitary axis was capable of recovery without any difference between the 2 techniques. Very few patients normalized or improved in the group presenting with a total anterior pituitary deficit.

*Postoperative Complications*

There were no postoperative deaths in this series. Complications are summarized in Table 5. In the entire series, the main difference between the 2 groups concerned CSF leaks (including intra- and postoperative, spontaneous and provoked, minor and major). Cerebrospinal fluid leakage occurred in 7 patients (8.5%) from Group B, all of whom were treated with lumbar drainage, and in 10 patients (12.1%) from Group A, 9 of whom were successfully treated with lumbar drainage for 5–8 days and the other with a second surgery for reconstruction of the sellar defect. During surgery, a persistent fistula was detected at the superior part of the sellar due to inferior

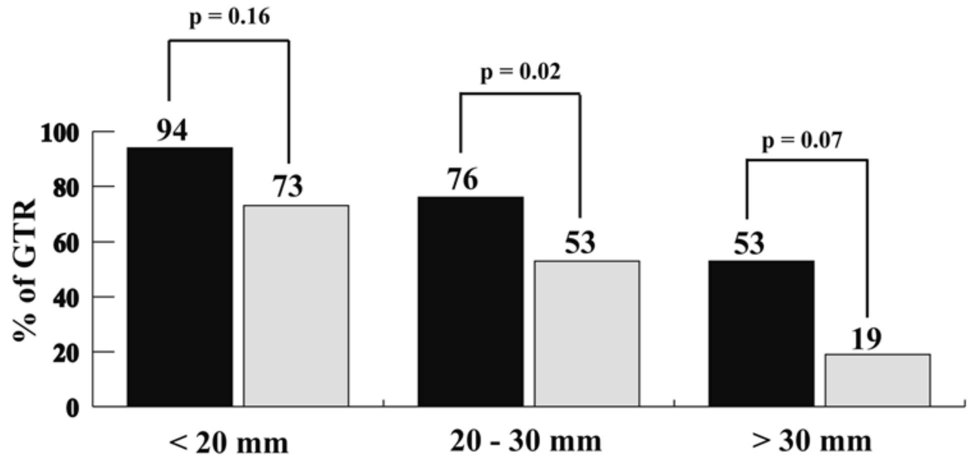


**Fig. 1.** Bar graph demonstrating the rate of GTR according to tumor height. Whatever the height of the adenoma, the gain of vision provided by straight and angled endoscopes *(black bar)* improved control of the suprasellar part of the tumor as compared with the microscopic procedure *(white bar)*. Clinical benefit increased with the height of macroadenomas, although only significantly for the group of tumors between 20 and 30 mm.

migration of the graft positioned during the first surgery. Additional fat graft and fibrin glue were used, and an intrasphenoidal balloon was inserted for 3 days to avoid such a migration.

## Discussion

Though only recently introduced to pituitary surgery, endoscopy is fast becoming the technique of choice at more and more neurosurgical centers.[5,6,11,15,24,38] Combined with the endonasal approach, this technique undoubtedly allows a relatively painless postoperative course for patients.[6,8,10] However, its superiority is still under debate in the absence of randomized studies and few series published to date.[10,11,15,39]

Nonfunctioning pituitary adenomas together comprise the gonadotrophic (FSH, LH, α–subunit immunostaining), immunonegative (no immunostaining), and silent adenomas (PRL, TSH, ACTH, and GH immunostaining without clinical symptoms).[1] While these adenomas are different in terms of their growth behavior,[28] all represent the same challenge for the neurosurgeon. Indeed, such macroadenomas, for which there is no efficient medical therapy, must be removed via radical surgery whenever possible. Considering the literature reports of postoperative residue in 35.5%–74% of cases treated using a microscopic technique[13,14,30,33,35,37,40] and our own experience of only a 50% rate of GTR, there is clearly room for refinement. Our main goal was to investigate whether endoscopy does indeed contribute toward the improved removal of NFPAs. To this end, we compared 2 homogeneous groups of patients consecutively treated at our institution by the same experienced surgeons within a short period of time, excluding patients with recurrent tumors, which are rarely accessible for radical removal. To our knowledge, this is the first study comparing the 2 techniques performed by the same neurosurgeons in a large series of NFPAs (Table 6).

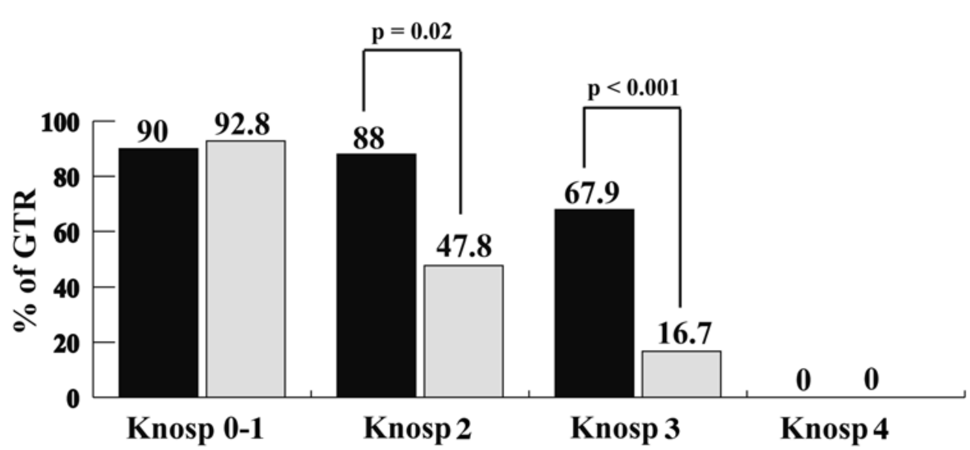


**Fig. 2.** Bar graph showing the rate of GTR according to lateral extension. Similar results were obtained with the 2 techniques (*black bar,* endoscopic procedure; *white bar,* microscopic procedure) for Grade 0–1 and Grade 4 tumors. More interesting were the results obtained for Grade 2 and 3 tumors, which extended laterally. The endoscope offered a better lateral view and thus improved lateral control of the tumor. Grade 2 tumors, like Grade 0–1 lesions, are probably noninvasive and are just pushing away the medial wall of the cavernous sinus, although microscopic invasion cannot be excluded. Actual invasion seems to occur at the Grade 3 level but only for one-third of the tumors.

**TABLE 3: Postoperative ophthalmological status**

| Before Op | After Op | Endoscopic Op | Microscopic Op | p Value |
|---|---|---|---|---|
| normal vision (%) | stable | 25/25 (100) | 20/20 (100) | 1 |
| visual impairment (%) | worsened | 0 | 1/62 (2) | 0.35 |
| | stable | 0 | 3/62 (5) | |
| | improved | 29/57 (51) | 31/62 (50) | |
| | normalized | 28/57 (49) | 27/62 (43) | |

As mentioned above, NFPAs are difficult to remove because of their suprasellar and lateral extension.[19] In our experience, the use of 0° and angled endoscopes able to explore the entire surgical field improves tumor control and allows 74% total removal, which is comparable with rates in the "endoscopic" literature (56%–93%),[3,11,15,22,29,30] as opposed to 50% total removal via microsurgery, which is comparable with rates in the "microscopic" literature (35%–74%; Table 6).[13,14,30,33,37,40] Whatever the height of the adenoma, endoscopy improved control of the suprasellar part, with only 5 noncompressive residues in Group A versus 10 residues in Group B, 3 of which needed reoperation due to persistent compressive effect. Endoscopy also helped us gain control over lateral extension of the tumor. The medial wall of the cavernous sinus cannot be seen on the 1.5-T MR imaging used in this study. Indirect arguments are therefore required to quantify this important point. The Knosp classification[31] was used as a simple and easy method of quantifying cavernous sinus invasion. Based on a tumor's relation to the carotid lines, Knosp et al.[31] defined 4 grades. Grade 0–1 lesions are clearly noninvasive and accessible for complete removal. In that subgroup of tumors, in which adenomas are mostly intrasellar, both techniques produced similar results with 90% GTR. When the tumor undoubtedly invaded the cavernous sinus (Grade 4), as expected, whichever technique was used, the tumor removal was always subtotal. More interesting are the Grade 2 and 3 groups, within which the tumor crosses the cross-sectional centers of the intra- and supracavernous ICA. In Knosp and colleagues' original study, these tumors were considered as invading the cavernous sinus. Our results obtained with endoscopy (88% and 67.9% GTR for Grade 2 and 3 tumors, respectively), when compared with those achieved with microsurgery (47.8% and 16.7%, respectively), clearly demonstrated the improvement in terms of the visual field offered by the endoscope, which enabled increased lateral exploration and thus a more efficient and safe removal of the adenoma. Our results do, however, raise an important debate regarding actual invasion of the cavernous sinus by such adenomas. Grade 2 lesions, with the same rate of GTR as the Grade 0–1 lesions, are probably noninvasive and just pushing away the medial wall of the cavernous sinus, although a microscopic invasion cannot be excluded. Actual invasion seems to occur at the Grade 3 level, at which one-third of the tumors in our endoscopy group were subtotally removed. We were unable to correlate the Knosp grading with the perioperative aspect of the medial wall of the cavernous sinus as some data were missing. However, a prospective study of this topic is ongoing.

**TABLE 4: Postoperative endocrinological outcome***

| Before Op | After Op | Endoscopic Op | Microscopic Op | p Value |
|---|---|---|---|---|
| normal (%) | | 37 | 31 | 0.14 |
| | unchanged | 32 (86.5) | 22 (71) | |
| | worsened | 5 (13.5) | 9 (29) | |
| PAPI (%) | | 32 | 41 | 0.01 |
| | worsened | 7 (22) | 12 (29) | |
| | unchanged | 7 (22) | 19 (46) | |
| | improved | 2 (6) | 4 (10) | |
| | normalized | 16 (50) | 6 (15) | |
| TAPD (%) | | 13 | 10 | 0.8 |
| | unchanged | 10 (76.9) | 6 (60) | |
| | improved | 2 (15.4) | 3 (30) | |
| | normalized | 1 (7.7) | 1 (10) | |

* PAPI = partial anterior pituitary insufficiency; TAPD = total anterior pituitary deficiency.

**TABLE 5: Postoperative complications***

| Complication | No. (%) Endoscopic Op | Microscopic Op | p Value |
|---|---|---|---|
| death | 0 | 0 | |
| epistaxis | 4 (4.9) | 1 (1.2) | 0.37 |
| CSF leakage | 10 (12.1) | 7 (8.5) | 0.33 |
| meningitis | 3 (3.7) | 4 (4.9) | 1 |
| definitive DI | 7 (8.5) | 8 (9.8) | 1 |
| hematoma | 0 | 1 (1.2) | 1 |
| CN III transient palsy | 0 | 2 (2.4) | 1 |

* DI = diabetes insipidus.

Nevertheless, we are aware that this study has some weaknesses. First, it is a retrospective and not a randomized study, difficult to design in practice. Second, the neuronavigation system was used only for the patients in Group A, primarily to guide the endonasal step. In our opinion, this had a minor if any impact on the tumor results, as the neuronavigation quickly becomes unreliable because of the shift issue once tumor removal begins. Third, we cannot exclude that the differences observed between the 2 groups in terms of the quality of tumor resection is attributable to the increased experience of the surgeon. However, the included microscopic cases were the latest after more than 1300 cases treated previously at our center. On the other hand, all patients in the endoscopy group were taken into account, including those treated at the beginning of our endoscopic experience, which might have negatively affected the results of Group A. Finally, our findings support those of others arguing in favor of a beneficial impact of endoscopy on pituitary surgery, with higher rates of GTR in the endoscopic series compared with the microscopic one (Table 6). However, while endoscopy does appear to improve immediate surgical outcome with fewer postoperative residues on MR

**TABLE 6: Quality of tumor removal in NFPA series following endoscopy and microsurgery***

| Authors & Year | No. of NFPA Cases | No. of CSI Cases (%) | % GTR of All Endoscopy Cases | % GTR of All Microsurgery Cases |
|---|---|---|---|---|
| Ebersold et al., 1986 | 100 | unknown | NA | 50.0 |
| Saito et al., 1995 | 100 | unknown | NA | 74.0 |
| Zhang et al., 1999 | 208 | unknown | NA | 70.2 |
| Jho et al., 2001[22] | 68 | unknown | 78 | NA |
| Cappabianca et al., 2002[3] | 80 | 19 (24) | 56 | NA |
| Kabil et al., 2005 | 161 | unknown | 93 | NA |
| Mortini et al., 2005 | 378 | unknown | NA | 64.8 |
| Ferrante et al., 2006 | 295 | unknown | NA | 35.5 |
| Frank et al., 2006 | 173 | 35 (20) | 76.9 | NA |
| Dehdashti et al., 2008 | 111 | 10 (9) | 88 | NA |
| present study | 164 | 16 (19.5)†; 20 (24.5)‡ | 74 | 50.0 |

* CSI = cavernous sinus invasion; NA = not applicable, technique not used.
† Endoscopy group.
‡ Microscopy group.

imaging, further studies with large multicentric cohorts are warranted to demonstrate the real impact of such a technique on long-term recurrence, which is the main issue with such adenomas.

With regards to the ophthalmological outcome, the 2 techniques were similar. Patients can therefore expect to recover enough vision to resume a normal life except in the rare event of optic nerve atrophy or complications (none in our endoscopic group). This finding is in accordance with reports in the literature. Indeed, Frank et al.[15] reported 94.7% normalization or improvement, 3.8% stabilization, and 1.2% worsening; Tabaee et al.[39] reported 92% complete resolution or significant improvement with no experience of worsening; and Dehdashti et al.[11] reported 91% normalization or improvement and 9% stabilization.

More interesting is the endocrinological outcome. In more aggressive tumor removal using the endoscope, one might expect more significant pituitary deficiency. In our experience, however, during surgery in many cases, a thin layer of anterior pituitary tissue can be seen after removing the tumors with the endoscope pushed inside the sella (never seen during microscopic surgery), suggestive of better-preserved pituitary function. Thus, using the endoscopic technique, less aggravation and significantly more improvement has been observed mainly in the group experiencing partial anterior deficits (56% normalized or improved in the endoscopic group compared with 25% in the microscopic surgery group, $p = 0.01$). In the literature, while numerous studies have been published on the endocrinological outcome of hypersecretion syndromes in patients with pituitary adenomas, only a few have focused on the impact of NFPA surgery on pituitary function. The largest study was published by Nomikos et al.[35] who described the endocrinological outcome of 660 NFPAs surgically removed via the microscopic technique with a 12-month follow-up. Patients with partial anterior pituitary insufficiency normalized or improved in 49.7% of cases, remained stable in 48.9%, and worsened in 1.4%. Two other studies of microscopically removed NFPAs, one by Nelson et al.[34] (among 83 patients, 35% improved, 32.1% worsened, and 32.1% stabilized), and another by Jane and Laws[20] (among 1000 patients, 27% improved), reported less optimistic results that more closely resemble our own experience (improved or normalized in 25%, unchanged in 46%, and worsened in 29%). Endocrinological data for endoscopy in NFPA surgery are sparse. While no definitive conclusions can yet be drawn from our observations, endoscopy does seem to improve the preservation of pituitary function. Finally, permanent diabetes insipidus is not rare in the postoperative course of such macroadenoma removals, in which the posterior pituitary has in most cases completely disappeared.

With regards to surgical morbidity, CSF leaks seem to be the most common and disturbing complication for pituitary surgeons and their patients. In comparing the 2 techniques at our institution, CSF leaks were observed in 12.1% and 8.5% respective cases using the endoscopic and microscopic technique (p = not significant). It should be noted that most CSF leaks were minor and easily managed with packing and CSF diversion. In the largest endoscopic study in the literature, the percentage of CSF leaks ranged from 1.6% to 5.2%,[3,29,39] lower rates than that reported here. In a series of 592 pituitary macroadenomas and giant pituitary adenomas removed via the microscopic technique, Han et al.[17] reported postoperative CSF leaks in 4.4% of patients and described a correlation between the risk of CSF leaks and the type of adenoma, its consistency, margins, and size. The same prognostic markers were observed in our study (data not shown). The difference between our observations and those of others can be at least partly explained by the heterogeneity of the series, that is, grouping together macro- and microadenomas and secreting or nonsecreting tumors. In addition, only significant CSF leaks are often taken into account in the literature. Ciric et al.[9] published the results of a survey of American neurosurgeons, including the surgical results of 958 neurosurgeons, and reported CSF leaks in 1.5% of cases (mixing all types of adenomas).

These results clearly demonstrate that the percentage risk of CSF leakage, as with other side effects of surgery, can be dramatically decreased with experience. However, this learning curve is unavoidable whatever the surgical technique.[3,12,36] Experience can be gained fairly rapidly given that in the present study the 22% incidence of CSF leaks in the first 41 operations with the endoscope was reduced to 7.3% for the last 41 operations and is still decreasing, currently at 5% in macroadenomas after more than 400 procedures to date. Meningitis, a potentially fatal complication, can be caused by a CSF leak or can occur after lumbar drainage, although it can usually be easily treated with antibiotics. Seven patients in the present series (4% of patients on average) presented with symptoms of and CSF analyses compatible with meningitis, with no difference between the techniques. According to the literature, for either endoscopy[3,11] or microscopic surgery,[9] the risk is around 1%. About half of our meningitis cases were caused by contamination by a lumbar drain probably kept in place too long. We have now changed our protocol and perform lumbar drainage over a shorter period of time and only for severe CSF leakage. Pursuing this course has contributed to a decreased incidence of meningitis in our more recent cases to within the range observed in the literature.

A special note should be made of the epistaxis that can occur with an endonasal route (about 1% in the literature[11,15] and 5% in our endoscopic group). Great care should be taken to avoid the posterior nasal and sphenopalatine arteries situated below the ostium and behind the posterior part of the middle turbinate, respectively. Indeed, the epistaxis encountered in our study arose following injury to these arteries when the lateral recess of the sphenoid was systematically opened and the mucosa was cut from the ostium down to the choana with minimal cauterization. Cauterization of these arteries when a large opening of the sphenoid sinus is required completely resolves this issue.

## Conclusions

In this large series of patients with NFPAs, endoscopy has proven to be more efficient than microscopic surgery in terms of the quality of resection and the endocrinological outcome. We therefore recommend that endoscopy be considered as the choice technique for removing such pituitary tumors. Further studies with long-term follow-up are ongoing to establish whether these encouraging results for the short term have a positive impact on long-term tumor recurrence for the different subtypes of NFPAs, a critical issue with such adenomas.

#### Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Jouanneau. Acquisition of data: Jouanneau, Messerer, De battista, Kassis, Dubourg. Analysis and interpretation of data: Jouanneau, Messerer, Lapras, Dubourg, Perrin. Drafting the article: Jouanneau, Messerer, Dubourg. Critically revising the article: Jouanneau, Messerer, Raverot, Trouillas. Reviewed final version of the manuscript and approved it for submission: Jouanneau, Messerer, Raverot, Trouillas, Perrin. Statistical analysis: Dubourg. Study supervision: Jouanneau.

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# Nasal symptoms following endoscopic transsphenoidal pituitary surgery: assessment using the General Nasal Patient Inventory

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*Object.* The endoscopic approach for pituitary tumors is a recent innovation and is said to reduce the nasal trauma associated with transnasal transsphenoidal surgery. The authors assessed the temporal changes in the rhinological symptoms following endoscopic transsphenoidal surgery for pituitary lesions, using the General Nasal Patient Inventory (GNPI).

*Methods.* The GNPI was administered to 88 consecutive patients undergoing endoscopic transsphenoidal surgery at 3 time points (presurgery, 3–6 months postsurgery, and at final follow-up). The total GNPI score and the scores for the individual GNPI questions were calculated and differences between groups were assessed once before surgery, several months after surgery, and at final follow-up.

*Results.* Of a maximum possible score of 135, the mean GNPI score at 3–6 months postsurgery was only 12.9 ± 12 and was not significantly different from the preoperative score (10.4 ± 13) or final follow-up score (10.3 ± 10). Patients with functioning tumors had higher GNPI scores than those with nonfunctioning tumors for each of these time points ($p < 0.05$). Individually, a mild increase in symptom severity was seen for symptoms attributable to the nasal trauma of surgery, with partial recovery (nasal sores and bleeding) or complete recovery (nasal blockage, painful sinuses, and unpleasant nasal smell) by final follow-up ($p < 0.05$). Progressive improvements in symptom severity were seen for symptoms more attributable to tumor mass preoperatively (for example, headaches and painkiller use [$p < 0.05$]). In total, by final follow-up 8 patients (9%) required further treatment or advice for ongoing nasal symptoms.

*Conclusions.* Endoscopic transsphenoidal surgery is a well-tolerated minimally invasive procedure for pituitary fossa lesions. Overall patient-assessed nasal symptoms do not change, but some individual symptoms may show a mild worsening or overall improvement. *(DOI: 10.3171/2011.1.FOCUS10319)*

**Key Words** • **endoscopic transsphenoidal surgery** • **pituitary tumor** • **nasal symptoms**

The endoscopic approach for pituitary tumors is a recent innovation, and there are now several reports of patients in whom the endoscopic transnasal transsphenoidal route was used, with claims of benefits for the surgeon and patient.[2,13,17] Apart from the improved visualization provided by both a wider field of view and focused illumination, the endoscopic approach is also claimed to be associated with fewer nasal complications.[2,6,19]

Outcome measures following transsphenoidal surgery have traditionally included the following: assessment of the reversal of visual field deficits, extent of MR imaging–documented tumor resection, and the remission rates for functioning adenomas. These measures focus primarily on the clinician's perspective of the patient's illness but may not take into account the patient's concerns with his or her own health. Patient-based questionnaires are increasingly being validated for use as outcome measures, providing individualized evaluation of the success of the given therapy.[1,11]

The GNPI is a patient-oriented, general nasal symptom questionnaire that has been validated in large numbers of patients with rhinological concerns.[7] It represents a comprehensive 45-item questionnaire, encompassing a vast array of nasal complaints perceived as important by patients (Table 1). It is a sensitive tool in assessing pre- and postoperative nasal symptoms following any nasal intervention.[3] In this study, we administered the GNPI to patients undergoing endoscopic transsphenoidal pituitary surgery, and we report on the temporal changes in patient-perceived rhinological symptoms.

*Abbreviation used in this paper:* GNPI = General Nasal Patient Inventory.

**TABLE 1: Percentages of patients selecting each severity GNPI grade for symptoms at 3 time points***

| | | Percentage of Patients Selecting Grade | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Preop | | | | 3–6 Mos Postop | | | | 6–24 Mos Postop | | | | p |
| | Symptom | 0 | 1 | 2 | 3 | 0 | 1 | 2 | 3 | 0 | 1 | 2 | 3 | Value† |
| 1 | I have sores inside my nose | 99 | 1 | 0 | 0 | 84 | 9 | 7 | 0 | 90 | 10 | 0 | 0 | 0.001 |
| 2 | I get headaches | 53 | 7 | 15 | 25 | 69 | 11 | 13 | 7 | 75 | 5 | 14 | 6 | 0.002 |
| 3 | I take too many painkillers | 86 | 2 | 4 | 8 | 92 | 7 | 1 | 0 | 94 | 5 | 1 | 0 | 0.01 |
| 4 | There is an unpleasant smell in my nose | 96 | 3 | 1 | 0 | 78 | 6 | 11 | 5 | 90 | 5 | 4 | 1 | 0.01 |
| 5 | My nose bleeds | 97 | 1 | 2 | 0 | 83 | 9 | 4 | 4 | 84 | 12 | 4 | 0 | 0.02 |
| 6 | My sinuses are painful | 86 | 12 | 1 | 1 | 87 | 2 | 10 | 1 | 90 | 6 | 2 | 2 | 0.02 |
| 7 | My nose is blocked | 77 | 10 | 9 | 4 | 60 | 15 | 15 | 10 | 73 | 15 | 12 | 0 | 0.03 |
| 8 | I feel dripping at the back of my nose | 98 | 2 | 0 | 0 | 89 | 8 | 3 | 0 | 95 | 4 | 0 | 1 | 0.07 |
| 9 | I have an unpleasant taste in my mouth | 96 | 2 | 1 | 1 | 82 | 8 | 9 | 1 | 91 | 5 | 3 | 1 | 0.08 |
| 10 | I have feelings of nausea | 90 | 2 | 5 | 3 | 84 | 9 | 7 | 0 | 89 | 7 | 4 | 0 | 0.11 |
| 11 | My mouth is dry | 86 | 7 | 6 | 1 | 71 | 10 | 9 | 10 | 74 | 11 | 14 | 1 | 0.12 |
| 12 | My nose feels uncomfortable | 94 | 5 | 0 | 1 | 85 | 9 | 6 | 0 | 89 | 9 | 2 | 0 | 0.17 |
| 13 | My taste is affected | 96 | 1 | 2 | 1 | 84 | 5 | 8 | 3 | 94 | 3 | 2 | 1 | 0.22 |
| 14 | My work is affected | 83 | 1 | 2 | 14 | 84 | 4 | 6 | 6 | 85 | 3 | 6 | 6 | 0.27 |
| 15 | My voice changes | 93 | 2 | 4 | 1 | 87 | 11 | 1 | 1 | 87 | 11 | 1 | 1 | 0.28 |
| 16 | My jaws are sore | 96 | 1 | 1 | 2 | 93 | 6 | 1 | 0 | 95 | 5 | 0 | 0 | 0.28 |
| 17 | I feel tired | 45 | 18 | 15 | 22 | 38 | 23 | 23 | 16 | 41 | 26 | 23 | 10 | 0.30 |
| 18 | I have sore ears | 93 | 4 | 1 | 2 | 93 | 2 | 5 | 0 | 90 | 5 | 5 | 0 | 0.33 |
| 19 | My nose makes unusual noises | 98 | 1 | 1 | 0 | 91 | 6 | 3 | 0 | 93 | 5 | 2 | 0 | 0.42 |
| 20 | My sleep is disturbed | 71 | 11 | 9 | 9 | 72 | 8 | 16 | 4 | 74 | 10 | 12 | 4 | 0.47 |
| 21 | My nose is painful to touch | 97 | 1 | 2 | 0 | 90 | 6 | 3 | 1 | 91 | 6 | 3 | 0 | 0.48 |
| 22 | My sense of smell is affected | 90 | 5 | 3 | 2 | 78 | 12 | 8 | 2 | 82 | 10 | 7 | 1 | 0.50 |
| 23 | I have a choking feeling | 96 | 0 | 1 | 3 | 94 | 4 | 1 | 1 | 93 | 4 | 2 | 1 | 0.51 |
| 24 | My nose looks out of shape | 92 | 2 | 2 | 4 | 88 | 8 | 3 | 1 | 88 | 9 | 2 | 1 | 0.52 |
| 25 | I have sneezing attacks | 88 | 6 | 6 | 0 | 82 | 13 | 4 | 1 | 82 | 11 | 7 | 0 | 0.52 |
| 26 | I have pains in my face | 93 | 3 | 2 | 2 | 88 | 3 | 8 | 1 | 85 | 5 | 7 | 3 | 0.60 |
| 27 | I have to breathe through my mouth | 91 | 2 | 5 | 2 | 82 | 6 | 8 | 4 | 88 | 5 | 6 | 1 | 0.63 |
| 28 | I suffer from hayfever | 86 | 13 | 0 | 1 | 89 | 11 | 0 | 0 | 87 | 12 | 1 | 0 | 0.65 |
| 29 | I have difficulty breathing | 96 | 2 | 1 | 1 | 91 | 4 | 2 | 3 | 91 | 3 | 5 | 1 | 0.65 |
| 30 | I have difficulty talking or eating | 98 | 0 | 1 | 1 | 97 | 2 | 1 | 0 | 98 | 1 | 1 | 0 | 0.69 |
| 31 | I have sore, watering eyes | 83 | 11 | 4 | 2 | 80 | 12 | 8 | 0 | 80 | 11 | 8 | 1 | 0.70 |
| 32 | I feel moody, depressed, or irritable | 61 | 17 | 13 | 9 | 57 | 19 | 17 | 7 | 58 | 25 | 12 | 5 | 0.76 |
| 33 | My nose feels itchy | 91 | 7 | 2 | 0 | 85 | 9 | 6 | 0 | 88 | 8 | 4 | 0 | 0.77 |
| 34 | I am constantly sniffing | 87 | 6 | 6 | 1 | 83 | 11 | 5 | 1 | 84 | 11 | 5 | 0 | 0.80 |
| 35 | My hearing is affected | 94 | 2 | 4 | 0 | 94 | 4 | 2 | 0 | 93 | 4 | 2 | 1 | 0.84 |
| 36 | I speak through my nose | 92 | 7 | 1 | 0 | 89 | 9 | 1 | 1 | 93 | 6 | 1 | 0 | 0.86 |
| 37 | I have a sore throat | 89 | 7 | 4 | 0 | 90 | 5 | 5 | 0 | 93 | 4 | 2 | 1 | 0.86 |
| 38 | My gums bleed | 89 | 10 | 1 | 0 | 86 | 10 | 4 | 0 | 86 | 10 | 4 | 0 | 0.86 |
| 39 | I feel dizzy | 81 | 10 | 7 | 2 | 80 | 14 | 3 | 3 | 80 | 14 | 5 | 1 | 0.88 |
| 40 | I suffer from a cough | 89 | 9 | 0 | 2 | 89 | 7 | 3 | 1 | 90 | 8 | 1 | 1 | 0.90 |
| 41 | People ask me if I have a cold | 91 | 4 | 3 | 2 | 86 | 7 | 6 | 1 | 90 | 5 | 4 | 1 | 0.90 |
| 42 | My nose runs | 90 | 6 | 4 | 0 | 89 | 4 | 7 | 0 | 91 | 4 | 5 | 0 | 0.93 |
| 43 | I snore | 48 | 27 | 17 | 8 | 48 | 32 | 12 | 8 | 51 | 30 | 12 | 7 | 0.97 |
| 44 | I have bad breath | 94 | 2 | 2 | 2 | 90 | 5 | 3 | 2 | 93 | 4 | 2 | 1 | 0.97 |
| 45 | I get toothache | 89 | 6 | 2 | 3 | 90 | 6 | 2 | 2 | 92 | 4 | 2 | 2 | 0.99 |

* Grades are defined as the following: 0 = no symptom; 1 = mild symptom; 2 = moderate symptom; 3 = severe symptom.
† Pearson chi-square test.

## Methods

One hundred consecutive patients undergoing endoscopic transsphenoidal pituitary surgery were asked to participate after informed consent. For each patient, the clinical presentation, endocrine profile, visual field changes, MR imaging findings, operative details, complications, and tumor pathology were noted. Any history of nasal trauma or intervention was recorded.

*Operative Technique*

The endoscopic transnasal transsphenoidal approach we used has been described in detail.[15] Specifically, nasal preparation was performed with topical application of preoperative decongestants (cophenylcaine, Aurum Ltd.) into both nostrils. No antiseptic wash or injection of vasoconstrictors was used. A single-nostril approach is generally preferred with the side of access chosen following visual identification of the more capacious nasal passage or by the laterality of the lesion. The middle turbinate is gently deflected laterally to allow access. Turbinectomy (partial or total) is not undertaken. The posterior nasal mucosa overlying the anterior sphenoid wall and vomer is cauterized before opening the sphenoid sinus. The sphenoid sinus mucosa is usually retracted laterally using cotton patties. In the event of CSF leakage, a graded operative repair was undertaken using combinations of hemostatic gelatin sponge (Spongistan, Ethicon), dural substitute (Durafoam, Codman), periumbilical fat graft, and a dural sealant (Duraseal, Confluent Surgical).[18] Vascularized mucosal flaps are not used as part of our repair.[18] Patients undergoing extended transsphenoidal procedures were not included in this study.

Closure following tumor removal involves inspection of both nasal cavities to identify significant mucosal bleeding points that are controlled with diathermy. The deflected middle turbinate is medialized. Nasal packing is not routinely employed postoperatively, and the topical application of a nasal decongestant (xylometazoline 0.1% spray, Novartis) is prescribed for 7 days only. Postoperatively patients do not receive any other routine nasal treatment such as irrigation or debridement unless one is clinically deemed necessary.

*Nasal Symptoms*

The patients were asked to complete the GNPI questionnaire to assess nasal symptoms at 3 time points: preoperatively, 3–6 months postoperatively, and at final neurosurgical follow-up (Table 1). For each of the 45 items of the GNPI questionnaire the patient had to choose among 4 numerical answers (0 = not present, 1 = mild, 2 = moderate, and 3 = severe) (Table 1). Total scores (0–135) were graded per patient and per item, allowing assessment of global as well as specific changes in nasal symptoms over time.

*Statistical Analysis*

All data were entered and analyzed using the SPSS statistical package (Statistical Programs for the Social Sciences). Differences between groups were assessed using an ANOVA and post hoc Bonferroni tests for parametric data and using the chi-square tests for nonparametric data.

## Results

*Demographic and Pathological Data*

Of the 100 patients approached to participate in the study, 88 patients provided complete data, and the data obtained in these 88 patients were included in the present study. The mean age (± SD) of the patients was 51 ± 15 years (range 18–77 years), with a male preponderance (male/female ratio 1.4:1). The mean follow-up duration was 13 ± 4 months (range 6–23 months). Pituitary macroadenomas were present in 74 patients (84%), and the remaining tumors were as follows: 8 microadenomas, 5 cystic lesions (4 craniopharyngiomas and 1 Rathke cleft cyst), and 1 clival lesion. Surgery was performed for nonfunctioning pituitary adenomas in 54 cases (61%), hormone-secreting adenomas in 25 cases (28% [acromegaly in 14, Cushing disease in 5, prolactinoma in 4, and thyroid-stimulating hormone–secreting in 1]), and miscellaneous in 9 (10% [4 craniopharyngioma, 2 Rathke cleft cyst, and 4 apoplexy]). None of the patients underwent an extended transsphenoidal procedure.

Five patients underwent a redo transsphenoidal procedure, with the first procedure being a microscopic transsphenoidal operation performed by another surgeon in all cases. Of these patients, 2 had undergone radiotherapy following their original procedure. Intraoperative CSF leaks were seen in 22 patients (25%), with all leaks intraoperatively repaired using a combination of collagen sponge, hydrogel sealant, and occasionally periumbilical fat grafts when large arachnoid defects were noted.

*General Nasal Patient Inventory Scores*

Overall, there was no significant change in the total GNPI scores at 3–6 months or at final follow-up compared with the preoperative scores ($p = 0.3$, ANOVA) (Fig. 1). Functioning tumors were associated with higher GNPI scores than nonfunctioning tumors for each of these time points ($p < 0.01$, ANOVA) (Fig. 2). There was no significant difference between different types of functioning tumors. Other factors such as tumor size, intraoperative CSF leakage, and the nostril of approach did not affect the GNPI score (data not shown).

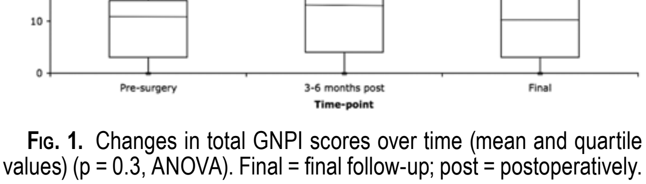


Fig. 1. Changes in total GNPI scores over time (mean and quartile values) ($p = 0.3$, ANOVA). Final = final follow-up; post = postoperatively.

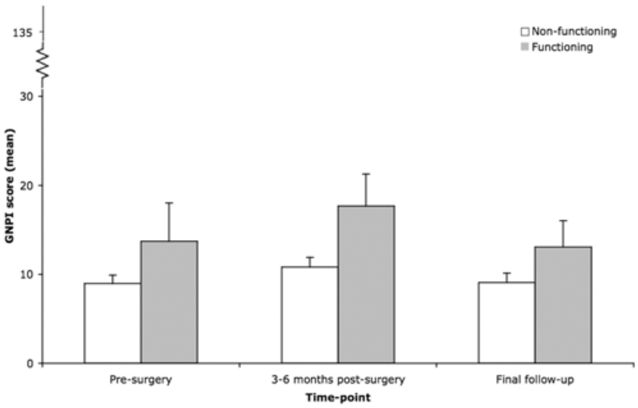


**Fig. 2.** Mean GNPI scores for functioning and nonfunctioning tumors over time. Functioning tumors were associated with a significantly higher GNPI score than nonfunctioning tumors at all time points ($p < 0.01$, ANOVA).

When considering the individual symptoms within the GNPI, several patterns of symptom progression were apparent over the study period. A transient worsening and partial reversal to preoperative levels were seen in response to questions related to nasal sores ($p < 0.01$) and nasal bleeds ($p < 0.05$, chi-square test) (Fig. 3C and D). A transient worsening and complete reversal to preoperative levels were seen in response to questions related to nasal blockage ($p < 0.05$), unpleasant nasal smells ($p < 0.01$), and painful sinuses ($p < 0.05$, chi-square test) (Fig. 3E and G). Progressive improvement in symptom severity was seen in response to questions related to headaches ($p < 0.01$) and painkiller usage ($p < 0.01$, chi-square test) (Fig. 3A and B).

By the final follow-up, 8 patients (9%) also required further clinical review for ongoing nasal symptoms such as nasal discharge/crusting (2 cases), blockage (2 cases), and intermittent bleeds (4 cases). These patients were managed with advice (4 cases), a course of steroid nasal sprays (2 cases), and cautery (2 cases).

## Discussion

Endoscopic transsphenoidal surgery is increasingly accepted as the first-line approach for sella region pathological entities.[3–5,8,14] Among the many purported advantages of endoscopic transsphenoidal surgery over microscopic approaches, one claim is a decrease in nasal trauma.[12] In endoscopic approaches, the avoidance of a rigid nasal speculum can help minimize the trauma and distortion of the nasal turbinates and septum. To our knowledge, thus far there has not been a quantitative study investigating patients' nasal symptoms following endoscopic transsphenoidal surgery. We present our findings after administering the GNPI to assess each patient's perspective of his or her postoperative nasal symptoms.

The GNPI was developed specifically to assess nasal symptoms in patients rhinological conditions.[7] This comprehensive 45-item inventory has been validated against the physician-derived 12-item Fairley nasal questionnaire.[10] It assesses the "success" of surgery from the patient's perspective and has been shown to be more sensitive to change after intervention than other available mea-

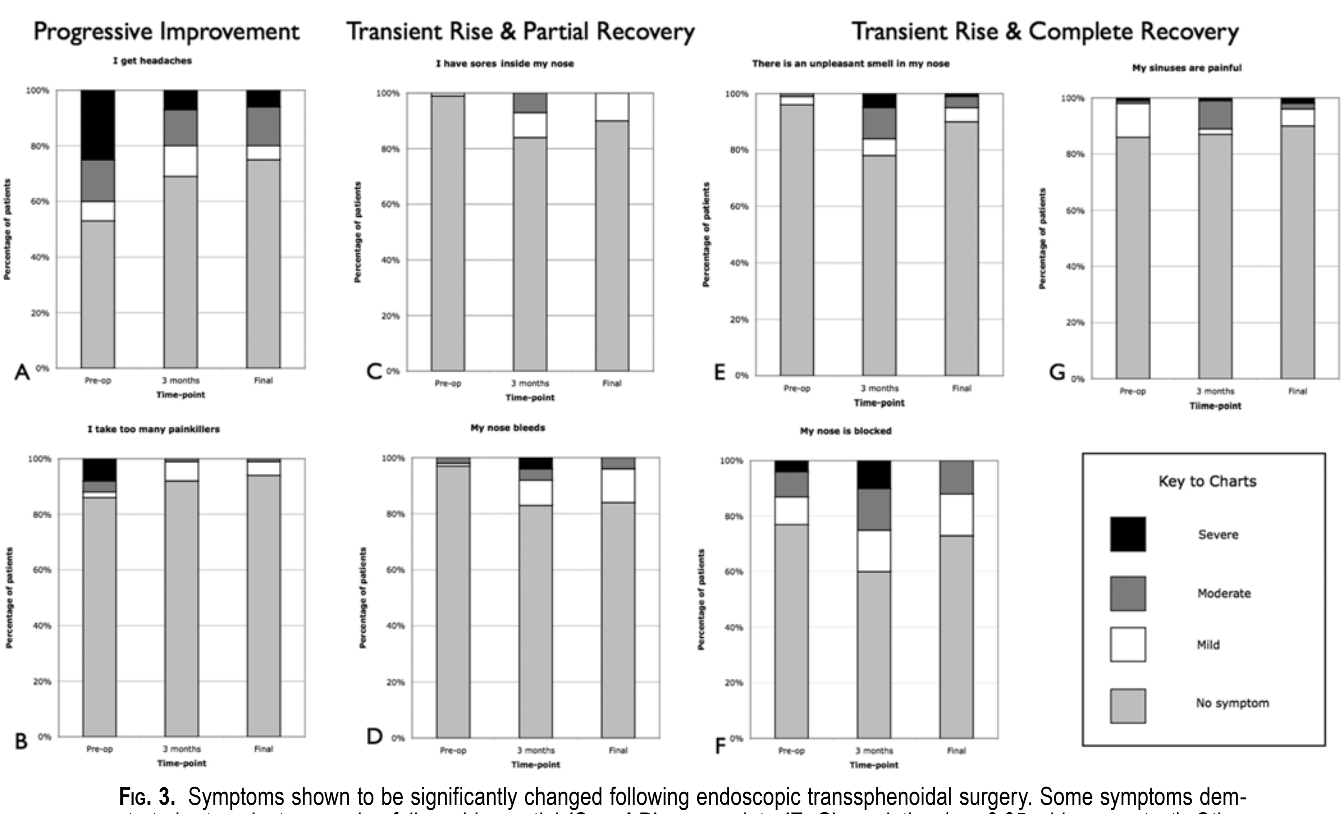


**Fig. 3.** Symptoms shown to be significantly changed following endoscopic transsphenoidal surgery. Some symptoms demonstrated a transient worsening followed by partial **(C and D)** or complete **(E–G)** resolution ($p < 0.05$, chi-square test). Other symptoms **(A and B)** showed a progressive improvement ($p < 0.05$, chi-square test).

sures.[7] Although the GNPI was not specifically devised for endoscopic pituitary surgery, given the commonality of the surgical approach it seems logical to use it in this context also.

Although the GNPI has a maximum total score of 135, the highest mean score recorded after endoscopic transsphenoidal surgery was only 13 (range 0–74) at 3–6 months postoperatively (Fig. 1). This was also not significantly different from the preoperative scores and would suggest that endoscopic pituitary surgery is associated with minimal disturbance to the nasal passages in the long run. Functioning adenomas were associated with a higher GNPI score than nonfunctioning tumors at all time points (Fig. 2). This may in part be attributed to the propensity for some functioning tumors, in particular growth hormone–secreting tumors, to present with nasal and upper-airway symptoms.

When individual nasal symptoms were taken into consideration, several patterns of symptom progression were apparent over the study period. By 3–6 months postoperatively, a small rise in some symptoms attributable to the nasal trauma of surgery was noted (Fig. 3). These symptoms had partially recovered (nasal sores and nasal bleeding) or fully recovered (nasal blockage, unpleasant nasal smells, and sinus pain) by final follow-up. Endoscopic transsphenoidal surgery approaches require some coagulation and disruption of the posterior nasal mucosa, and, on the one hand, it is likely that the mild rise in symptom severity is attributable to this. On the other hand, there was a progressive improvement in other symptoms such as headaches and analgesic use (Fig. 3). This may be attributable to the mass effect and/or hormonal activity of the tumor. However, for the vast majority of symptoms assessed in the GNPI, there was no significant change in the severity, further confirming the minimal disturbances to the nasal passages caused by the endoscopic approach.

Furthermore, only 9% of patients required further clinical review and/or minor interventions for ongoing problems such as nasal discharge, blockage, or intermittent nasal bleeds. We acknowledge that in the absence of routine postoperative rhinological inspections it is impossible to know the true incidence of such nasal complications. However, our data suggest that the rate of such complications appears to be low and intervention is rarely required.

Previous studies reporting on nasal symptoms after pituitary surgery have been largely qualitative in nature and undertaken by retrospective review of case records.[2,9,16,19] Moreover, the endoscopic approach is also claimed to be associated with fewer nasal complications compared with microscopic transsphenoidal approaches.[2,19] Localized nasal complications such as obstruction and crusting have been reported in up to 38% of microscopic transsphenoidal surgeries.[9,16] Dusick et al.[9] provided the only other quantitative assessment of the success of microscopic endonasal transsphenoidal surgery from the patients' perspective. They reported that by 3 months after microscopic transsphenoidal surgery, 67%–87% of patients had no rhinological complaints and concluded that rhinological recovery is rapid and relatively complete following microscopic endonasal transsphenoidal surgery. This is in keeping with the findings of the present study. It is difficult to compare the studies because of methodological differences, notably the use of 2 separate questionnaires.

## Conclusions

Endoscopic transsphenoidal surgery is well tolerated for sella and parasellar lesions. Overall nasal symptoms do not change, but some individual symptoms may show mild worsening and/or improvement.

#### Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Gnanalingham. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: Wang. Critically revising the article: Wang, Kearney, Gnanalingham. Reviewed final version of the manuscript and approved it for submission: Wang, Kearney, Gnanalingham. Statistical analysis: Wang, Gnanalingham. Study supervision: Gnanalingham.

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# Use of a side-cutting aspiration device for resection of tumors during endoscopic endonasal approaches

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*Object.* Accessing intra- and extradural tumors via an endonasal approach requires working safely in a relatively narrow area with unobstructed visibility. The authors describe their experience to highlight the utility of a side-cutting aspiration device for endoscopic endonasal resection of skull base tumors.

*Methods.* The authors used this device in 13 nonconsecutive endoscopic endonasal procedures for different skull base tumors (8 pituitary macroadenomas, 2 craniopharyngiomas, 1 chordoma, 1 recurrent ependymoma, and 1 lymphoma). Illustrative cases and video are presented to demonstrate its use.

*Results.* The instrument was easy to use and effective in the removal of the lesions presented in this series. In 10 patients (77%), gross-total resection was possible; in the other 3 patients (23%), more than 80% of the tumor was resected. No collateral tissue damage or any other complication resulted from device-related debulking or aspiration.

*Conclusions.* The side-cutting tissue resector is a safe, easy to use, and effective tool for internal debulking and extracapsular dissection of nonvascularized tumors that are too firm for bimanual suction or blunt ring curette dissection. It is particularly useful when working through a deep and narrow corridor such as is encountered in endoscopic endonasal skull base surgery. *(DOI: 10.3171/2011.1.FOCUS10302)*

**Key Words** • **skull base** • **endoscopy** • **minimally invasive procedure** • **craniopharyngioma** • **chordoma** • **transsphenoidal surgery**

The introduction of novel surgical approaches has always required the design and development of specific instruments based on the particular needs of the approach. The endonasal corridor is a long, narrow channel and the limited maneuverability requires the design of specific, dedicated instruments.[1]

One of the challenges of the endonasal endoscopic cranial base approach for resecting large, firm tumors has been the lack of adequate instruments to debulk the tumor. Although long narrow ultrasonic aspirators exist, their narrow center tube can clog with particulate material. Likewise, the tip of the instrument, where the aspiration occurs, is not easily visualized with a colinear, parallel endoscope, which provides better visualization for the side of the instrument.[4,5]

Craniopharyngiomas, adenomas, and chordomas have a recurrence rate directly correlated with the percent of resection.[11] An ideal instrument for achieving this goal using endoscopic visualization would be a long, narrow side-cutting instrument whose tip and noncutting side could be placed in proximity to critical neurovascular structures for resection of firm tumors in a narrow working space without heating the surrounding tissue.

## Methods

### *Equipment and Principles*

We used such a side-cutting aspiration system called the NICO Myriad (NICO Myriad System, NICO Corp.). The device is available in 3 lengths (10, 13, and 25 cm) and 2 cannula diameters (1.9 and 2.5 mm). The handpiece is shown in Fig. 1. The mechanism at the tip is based on a device that acts as an aspirator, tissue rake, and scissors. It is a disposable, nonheat-generating tissue removal system. It has an outer stationary cannula and a blunt atraumatic tip. An orifice on the side of the outer cannula is located several millimeters from the tip. A bladed inner cannula slides up and down within the outer cannula and is connected to a motor-driven handpiece. The functions of the device, suction, and blade action are controlled by a foot pedal, which can be variably depressed to regulate the degree of suction and the rapidity of the reciprocating blade. Tissue drawn into the central core by suction is cut by the reciprocating action of the bladed inner cannula (Fig. 1).[7] In addition, the tip can be bent up to 30° with a bending tool provided by the company, and tissue can be collected in a collection vat placed in-line with the suction of the device to collect tissue for pathological examination or a tumor bank.

*Patient Population*

We reviewed a prospectively collected database of all endoscopic endonasal surgeries performed at Weill Cornell Medical College, New York Presbyterian Hospital, between October 2009 and October 2010, as a collaboration between the neurosurgery and otolaryngology departments. Of the total 59 patients, 13 patients (22%) (with only giant pituitary adenomas, ependymomas, craniopharyngiomas, and chordomas) underwent endoscopic endonasal surgery in which the NICO Myriad system was used. The aformentioned tumors are generally firm and not amenable to just the 2-suction technique.

*Surgical Technique*

A surgical team that included an otolaryngologist (V.K.A.) and a neurosurgeon (T.H.S.) performed the extended endonasal surgeries at the Institute for Minimally Invasive Skull Base and Pituitary Surgery, Weill Cornell Medical College/New York Presbyterian Hospital. Institutional review board approval was obtained for the study. All procedures were performed using frameless stereotactic image guidance (BrainLab). The surgical technique for the endoscopic endonasal skull base approach has been described.[6,8–10] Once the approach was completed and the tumor exposed, the NICO Myriad was used to internally decompress the tumor in preparation for sharp extracapsular dissection (Video 1).

**Video 1.** Use of a side-cutting aspiration device for resection of tumors during endoscopic endonasal approaches. Click here to view with Windows Media Player. Click here to view with Quicktime.

## Results

We used the NICO Myriad in a series of 13 cases. The pathology of the cases is presented in Table 1. We found the instrument most helpful in the following situations. 1) Giant pituitary macroadenomas—these tumors tend to be very firm and difficult to resect with only ring curettes or straight suction. The NICO Myriad was extremely useful at internal decompression of these tumors so the capsule could be identified for extracapsular dissection (see Case 1). 2) Chordomas—these lesions can be soft and easily resected with suction or extremely firm and fibrous. In the latter case, the NICO Myriad is extremely useful to remove fibrous chordomas. In addition, the blunt tip of the device can be placed against the dura behind the clivus to remove the tumor and ensure that the dura is not opened inadvertently. 3) Craniopharyngiomas—the firm, solid parts of craniopharyngiomas, particularly those that extend into the third ventricle, can be difficult to remove with suction alone. The NICO Myriad can be bent upwards and placed into the third ventricle to remove solid intraventricular craniopharyngiomas via an endonasal approach (see Case 2).

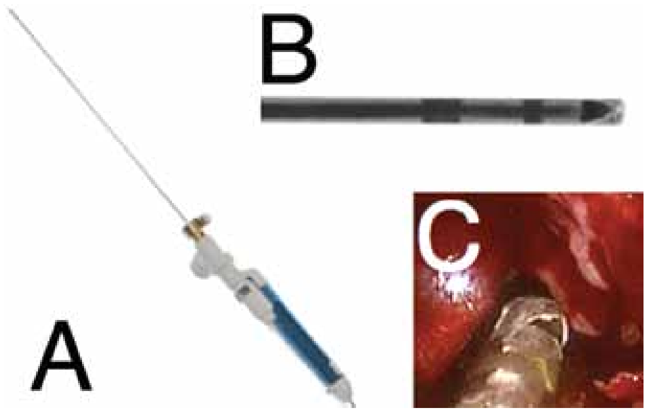


**Fig. 1. A:** Side-cutting aspiration device (handpiece). **B:** Close-up view of the nontraumatic blunt tip. **C:** The side port for aspiration of tissue.

The instrument was easy to use and effective in the removal of the lesions presented in this series, even when the consistency of the lesion was extremely firm and fibrous. In 6 of 8 adenomas, gross-total resection was performed. In both of the other cases the patients had cavernous sinus tumor extension, but more than 80% of the lesion was resected in each case. The clival chordoma, suprasellar craniopharyngioma, and recurrent ependymoma of the brainstem were totally resected. One patient diagnosed with lymphoma underwent partial resection. No intra- or postoperative complications occurred in this series. Closure was performed using either 1) a fat graft held in place with a Medpore (Porex Corp.) buttress covered with a nasoseptal flap and Duraseal (Confluent Surgical, Inc.) for adenomas with CSF leakage or 2) a gasket-seal closure covered with a nasoseptal flap and Duraseal for the craniopharyngioma. There were no postoperative CSF leaks.

## Illustrative Cases

*Case 1*

This 78-year-old man presented with progressive gait trouble, urinary incontinence, change in mental status, and bitemporal hemianopsia. A solid enhancing sellar-suprasellar mass and mild hydrocephalus were identified on MR imaging. An extended transsphenoidal approach was used with transtuberculum, transplanum removal. The tumor was first removed from within the sella. The optic chiasm was elevated and the tumor was removed from beneath the optic chiasm and the third ventricle. Internal decompression was performed until the walls of the third ventricle were identified and the tumor was considered to be completely removed. The foramina of Monro and the

**TABLE 1: Summary of tumor diagnosis, tumor extension, and extent of resection in 13 patients***

| Case No. | Diagnosis | Extension† | Consistence | Extent of Resection |
|---|---|---|---|---|
| 1 | macroadenoma | suprasellar- parasellar | firm | GTR |
| 2 | macroadenoma | parasellar (cav sinus) | soft | GTR |
| 3 | macroadenoma | parasellar (cav sinus) | extremely firm/fibrous | STR |
| 4 | macroadenoma | suprasellar | extremely firm/fibrous | GTR |
| 5 | macroadenoma | suprasellar | firm | GTR |
| 6 | macroadenoma | parasellar (cav sinus) | firm | STR |
| 7 | macroadenoma | suprasellar | soft | GTR |
| 8 | recurrent macroadenoma | suprasellar | extremely firm/fibrous | GTR |
| 9 | craniopharyngioma | suprasellar | extremely firm/fibrous | GTR |
| 10 | craniopharyngioma | suprasellar | extremely firm/fibrous | GTR |
| 11 | chordoma | clival: CVJ | extremely firm/fibrous | GTR |
| 12 | recurrent ependymoma | clival: brainstem | extremely firm/fibrous | GTR |
| 13 | lymphoma | suprasellar | firm | STR |

* cav = cavernous; CVJ = craniovertebral junction; GTR = gross-total resection; STR = subtotal resection.
† Parasellar includes into or beneath cavernous sinus, and anterior, middle, or posterior fossa extension.

choroid plexus were seen, and the skull base was closed (Fig. 2).

*Case 2*

This 60-year-old man had a history of craniopharyngioma, which was partially resected by bifrontal craniotomy and treated with CyberKnife 1 year prior to our evaluation. He presented with progressive visual reduction and diabetes insipidus. The patient underwent endoscopic gross-total tumor resection via a transsellar, transplanum, transtuberculum approach. The tumor was identified above the normal pituitary gland. It was dissected free from the surrounding structures and internally decompressed with the NICO Myriad device. Using a 30° endoscope, the lesion was dissected free from the optic chiasm and the cyst was removed from the third ventricle. The floor of the hypothalamus was free of tumor. The third ventricle was visualized superiorly. There was no evidence of residual tumor. The diagnosis was adamantinomatous craniopharyngioma (Fig. 3).

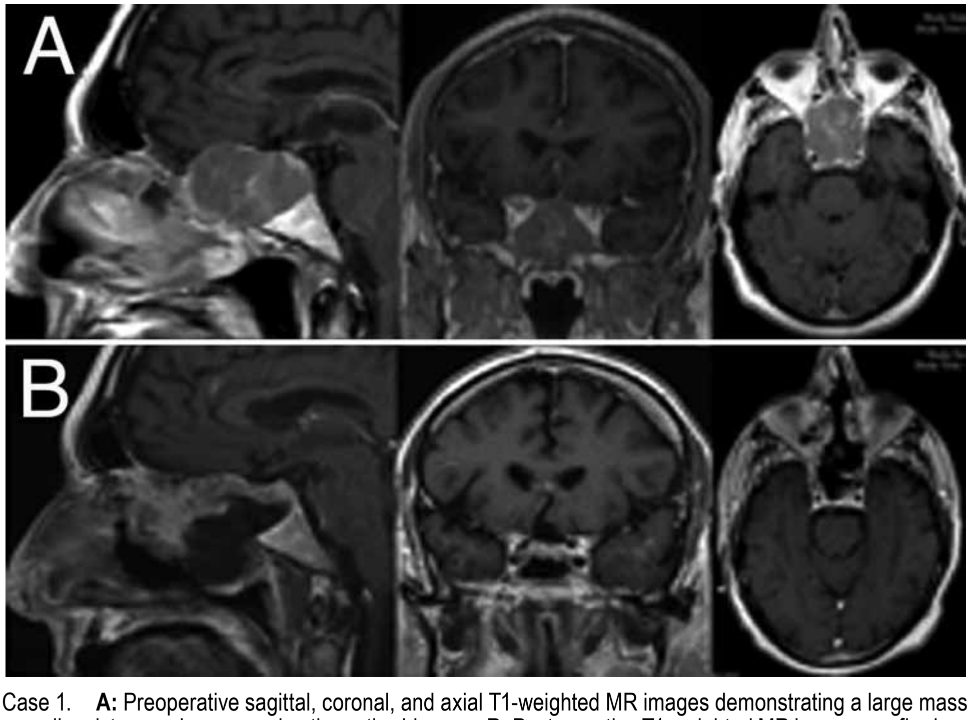


**Fig. 2.** Case 1. **A:** Preoperative sagittal, coronal, and axial T1-weighted MR images demonstrating a large mass extending into the suprasellar cistern and compressing the optic chiasm. **B:** Postoperative T1-weighted MR images confirming gross-total resection of the tumor.

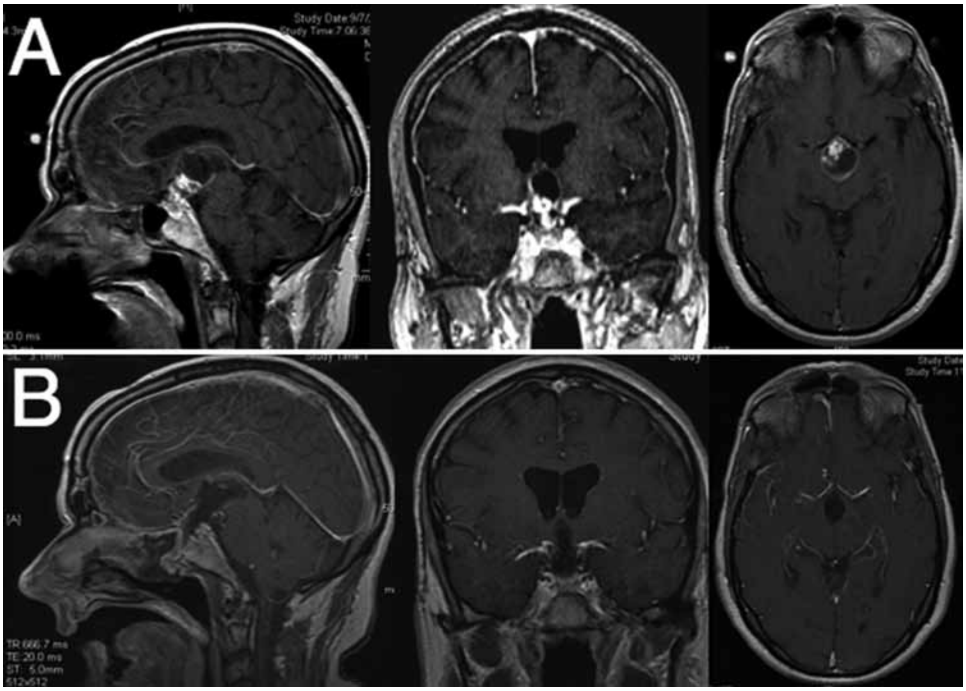

**Fig. 3.** Case 2. **A:** Preoperative sagittal, coronal, and axial T1-weighted MR images showing a mixed cystic and solid sellar and suprasellar mass and enhancement of the solid portion and the peripheral rim of the cystic portion. **B:** Postoperative T1-weighted MR images confirming gross-total resection of the tumor.

*Case 3*

This 68-year-old man developed diplopia 3 months before evaluation, which lasted 2 weeks and slowly resolved. After that he had pressure behind his right eye related to a headache, which was graded at 7/10. On physical examination he had an early upper temporal quadrantic visual loss. Magnetic resonance imaging revealed a large expansive and destructive mass, arising from an expanded sella and extending into the sphenoid sinus. There was extension into the anterior cranial fossa through a dehiscence of the ethmoid roof and cribriform plate. There was extraconal extension into the orbits.

An endoscopic endonasal approach, with sphenoidectomy and ethmoidectomy, was performed and the tumor was identified. The tumor was internally decompressed using the NICO Myriad. As the tumor was being debulked, the pathology report returned indicating a possible lymphoma and the resection was halted with some residual tumor left in the orbit and ethmoid roof (Fig. 4).

## Discussion

The most important criteria for new instrument design in endoscopic endonasal surgery are that the device: 1) move easily and safely in a limited surgical corridor, 2) be well balanced and ergonomic for safe handling, while avoiding any conflict between the surgeon's hands, the endoscope, and other instruments that may be present in the same nostril, and 3) allow the surgeon to work in every visible zone of the surgical field provided by the endoscope.[2,3,7]

The NICO Myriad tissue removal system is highly useful in tumor resection. It is lightweight, requires the use of only 1 hand, and features both tissue cutting and removal without the use of heat or ultrasonic energy, which reduces the chance of collateral damage. Because the end of the device is closed and blunt, there is little danger of injuring vessels or other fragile structures obscured from view by the instrument itself.[7] However, the surgeon must be aware of the possibility of adjacent tissue being aspirated into the device and causing iatrogenic damage. These complications can be avoided by intracapsular debulking of the tumor followed by extracapsular dissection. The NICO device is useful first to internally decompress firm tumors. We select this tool mainly for giant adenomas, chordomas, and craniopharyngiomas. We have found that these tumors are usually not amenable to resection using merely bimanual suction and blunt ring curette dissection. Once free of critical surrounding neurovascular structures, the NICO Myriad can be placed on the tumor capsule with the cutting side inwards and the noncutting side on the neurovascular structures to safely remove the remainder of the tumor. Alternating between these 2 techniques has been extremely valuable in removing large firm tumors. In addition, the NICO Myriad can be bent and the tip advanced up into the third ventricle. This maneuver is extremely useful for removing tumor fragments in the suprasellar cistern that may be beyond the reach of angled suctions.

Alternatives to the NICO Myriad are the ultrasonic aspirator, the Elliquence, and bimanual suction. In our experience, the transsphenoidal tips to the ultrasonic aspirator often clog with particulate material and their diameter is not as small and low profile as desired. The Elliquence is excellent for meningiomas that are too firm for the NICO Myriad and vascular but is not useful for

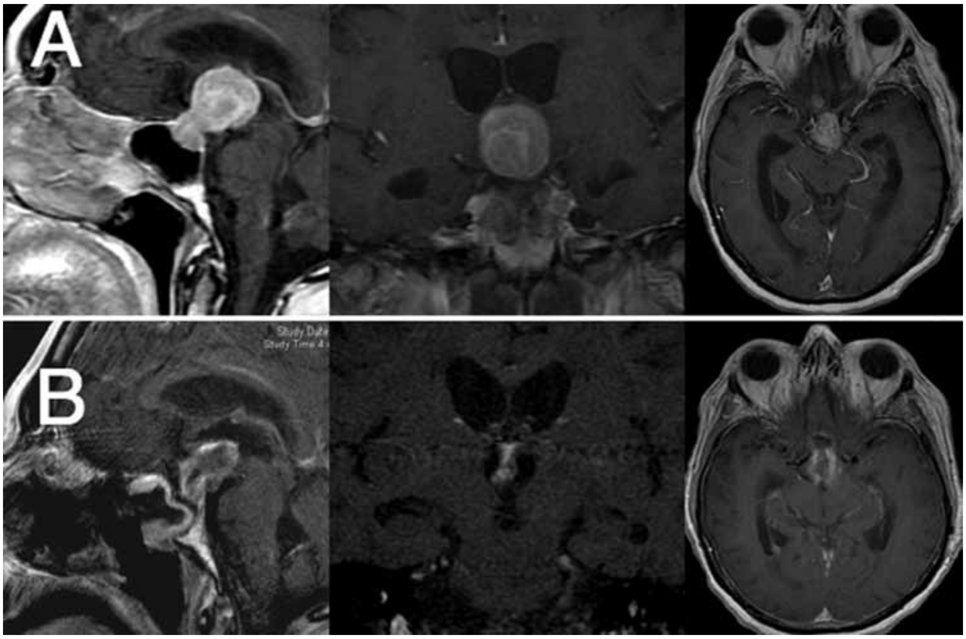


Fig. 4. Case 3. **A:** Preoperative sagittal, coronal, and axial T1-weighted MR images showing a large expansive and destructive mass extending into the sphenoid sinus, sellar and suprasellar area. **B:** Postoperative T1-weighted MR images confirming subtotal resection of the lesion.

tumors that are fibrous and avascular such as chordomas and macroadenomas. Bimanual suction is excellent for soft tumors, but once tumors become fibrous, this method often is not adequate. The NICO Myriad fills gaps in existing instrumentation.

The cost of the NICO Myriad is not insubstantial since there is a fixed cost for the main unit and additional costs for each disposable handpiece. We have found the NICO Myriad to be only useful for a small percentage of our cases, roughly 20%. However, for the cases in which the device was used, its use was thought to be almost essential to obtain a complete resection in a reasonable time period. For this reason, we feel that the NICO Myriad is worth the cost, even though it is only used in a subset of our cases. Whether the NICO Myriad leads to significant increases in extent of resection or survival is not known and would require a randomized trial. Such a trial will likely never be done, since it has not even been performed to justify the multimillion dollar acquisition of intraoperative MR imagers.

## Conclusions

The NICO Myriad tissue removal system is a safe, easy to use, and effective tool when used for internal debulking and extracapsular dissection of nonvascularized tumors that are too firm for bimanual suction or blunt ring curette dissection. It is particularly useful when working through a deep and narrow corridor such as is encountered in endoscopic endonasal skull base surgery.

#### Disclosure

The authors report no conflict of interest concerning the material or methods used in this study or the findings specified in this paper. None of the authors has any financial interest in any device discussed in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Garcia-Navarro, Guerrero-Maldonado, Schwartz. Acquisition of data: Garcia-Navarro, Lancman. Analysis and interpretation of data: Garcia-Navarro, Guerrero-Maldonado. Drafting the article: Garcia-Navarro, Lancman. Critically revising the article: Anand, Schwartz. Reviewed final version of the manuscript and approved it for submission: all authors. Administrative/technical/material support: Garcia-Navarro, Lancman. Study supervision: Anand, Schwartz.

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*Supplemental online information:*

Video: http://mfile.akamai.com/21490/wmv/digitalwbc.download.akamai.com/21492/wm.digitalsource-na-regional/focus10-302.asx (Media Player).

http://mfile.akamai.com/21488/mov/digitalwbc.download.akamai.com/21492/qt.digitalsource-global/focus10-302.mov (Quicktime).

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# Use of a side-cutting aspiration device for resection of tumors during endoscopic endonasal approaches

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*Results.* The instrument was easy to use and effective in the removal of the lesions presented in this series. In 10 patients (77%), gross-total resection was possible; in the other 3 patients (23%), more than 80% of the tumor was resected. No collateral tissue damage or any other complication resulted from device-related debulking or aspiration.

*Conclusions.* The side-cutting tissue resector is a safe, easy to use, and effective tool for internal debulking and extracapsular dissection of nonvascularized tumors that are too firm for bimanual suction or blunt ring curette dissection. It is particularly useful when working through a deep and narrow corridor such as is encountered in endoscopic endonasal skull base surgery. *(DOI: 10.3171/2011.1.FOCUS10302)*

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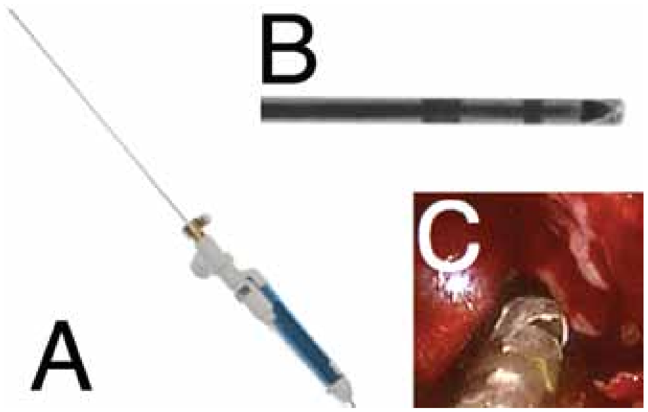


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*Case 2*

This 60-year-old man had a history of craniopharyngioma, which was partially resected by bifrontal craniotomy and treated with CyberKnife 1 year prior to our evaluation. He presented with progressive visual reduction and diabetes insipidus. The patient underwent endoscopic gross-total tumor resection via a transsellar, transplanum, transtuberculum approach. The tumor was identified above the normal pituitary gland. It was dissected free from the surrounding structures and internally decompressed with the NICO Myriad device. Using a 30° endoscope, the lesion was dissected free from the optic chiasm and the cyst was removed from the third ventricle. The floor of the hypothalamus was free of tumor. The third ventricle was visualized superiorly. There was no evidence of residual tumor. The diagnosis was adamantinomatous craniopharyngioma (Fig. 3).

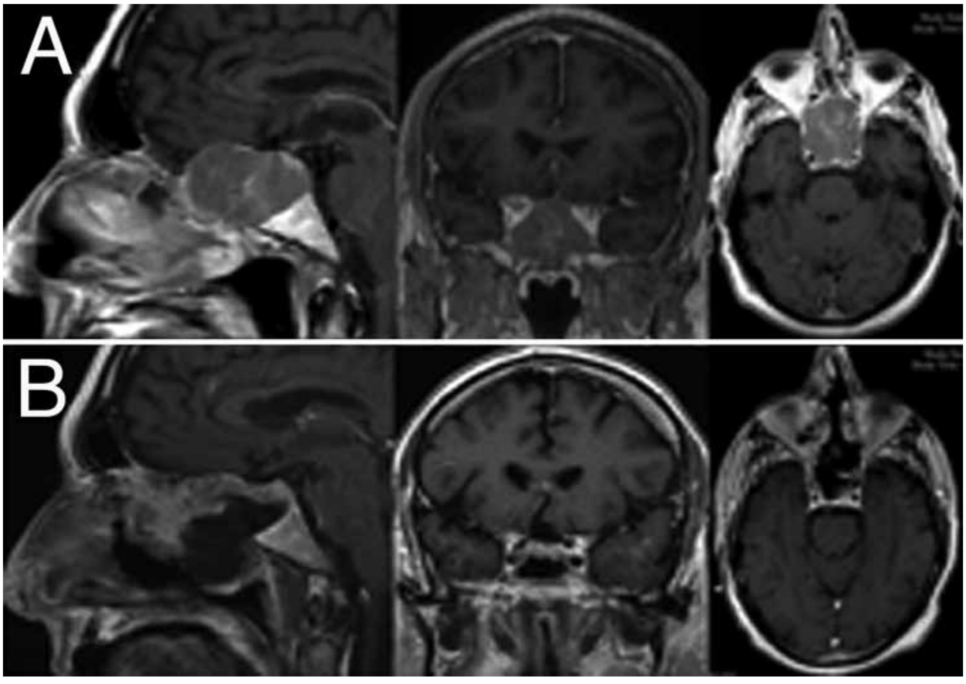


**Fig. 2.** Case 1. **A:** Preoperative sagittal, coronal, and axial T1-weighted MR images demonstrating a large mass extending into the suprasellar cistern and compressing the optic chiasm. **B:** Postoperative T1-weighted MR images confirming gross-total resection of the tumor.

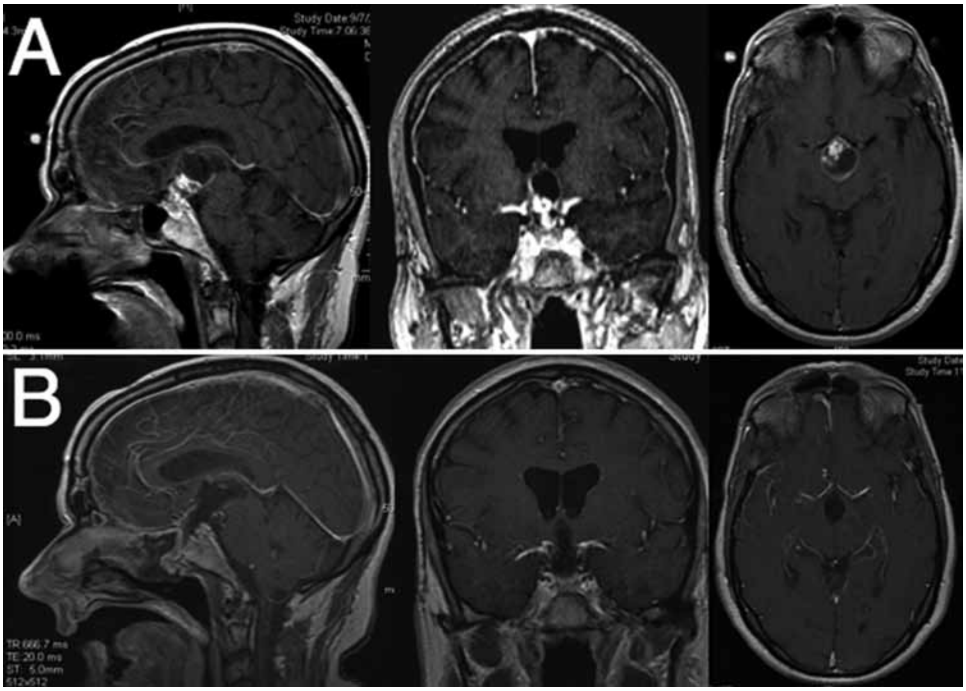


**Fig. 3.** Case 2. **A:** Preoperative sagittal, coronal, and axial T1-weighted MR images showing a mixed cystic and solid sellar and suprasellar mass and enhancement of the solid portion and the peripheral rim of the cystic portion. **B:** Postoperative T1-weighted MR images confirming gross-total resection of the tumor.

*Case 3*

This 68-year-old man developed diplopia 3 months before evaluation, which lasted 2 weeks and slowly resolved. After that he had pressure behind his right eye related to a headache, which was graded at 7/10. On physical examination he had an early upper temporal quadrantic visual loss. Magnetic resonance imaging revealed a large expansive and destructive mass, arising from an expanded sella and extending into the sphenoid sinus. There was extension into the anterior cranial fossa through a dehiscence of the ethmoid roof and cribriform plate. There was extraconal extension into the orbits.

An endoscopic endonasal approach, with sphenoidectomy and ethmoidectomy, was performed and the tumor was identified. The tumor was internally decompressed using the NICO Myriad. As the tumor was being debulked, the pathology report returned indicating a possible lymphoma and the resection was halted with some residual tumor left in the orbit and ethmoid roof (Fig. 4).

## Discussion

The most important criteria for new instrument design in endoscopic endonasal surgery are that the device: 1) move easily and safely in a limited surgical corridor, 2) be well balanced and ergonomic for safe handling, while avoiding any conflict between the surgeon's hands, the endoscope, and other instruments that may be present in the same nostril, and 3) allow the surgeon to work in every visible zone of the surgical field provided by the endoscope.[2,3,7]

The NICO Myriad tissue removal system is highly useful in tumor resection. It is lightweight, requires the use of only 1 hand, and features both tissue cutting and removal without the use of heat or ultrasonic energy, which reduces the chance of collateral damage. Because the end of the device is closed and blunt, there is little danger of injuring vessels or other fragile structures obscured from view by the instrument itself.[7] However, the surgeon must be aware of the possibility of adjacent tissue being aspirated into the device and causing iatrogenic damage. These complications can be avoided by intracapsular debulking of the tumor followed by extracapsular dissection. The NICO device is useful first to internally decompress firm tumors. We select this tool mainly for giant adenomas, chordomas, and craniopharyngiomas. We have found that these tumors are usually not amenable to resection using merely bimanual suction and blunt ring curette dissection. Once free of critical surrounding neurovascular structures, the NICO Myriad can be placed on the tumor capsule with the cutting side inwards and the noncutting side on the neurovascular structures to safely remove the remainder of the tumor. Alternating between these 2 techniques has been extremely valuable in removing large firm tumors. In addition, the NICO Myriad can be bent and the tip advanced up into the third ventricle. This maneuver is extremely useful for removing tumor fragments in the suprasellar cistern that may be beyond the reach of angled suctions.

Alternatives to the NICO Myriad are the ultrasonic aspirator, the Elliquence, and bimanual suction. In our experience, the transsphenoidal tips to the ultrasonic aspirator often clog with particulate material and their diameter is not as small and low profile as desired. The Elliquence is excellent for meningiomas that are too firm for the NICO Myriad and vascular but is not useful for

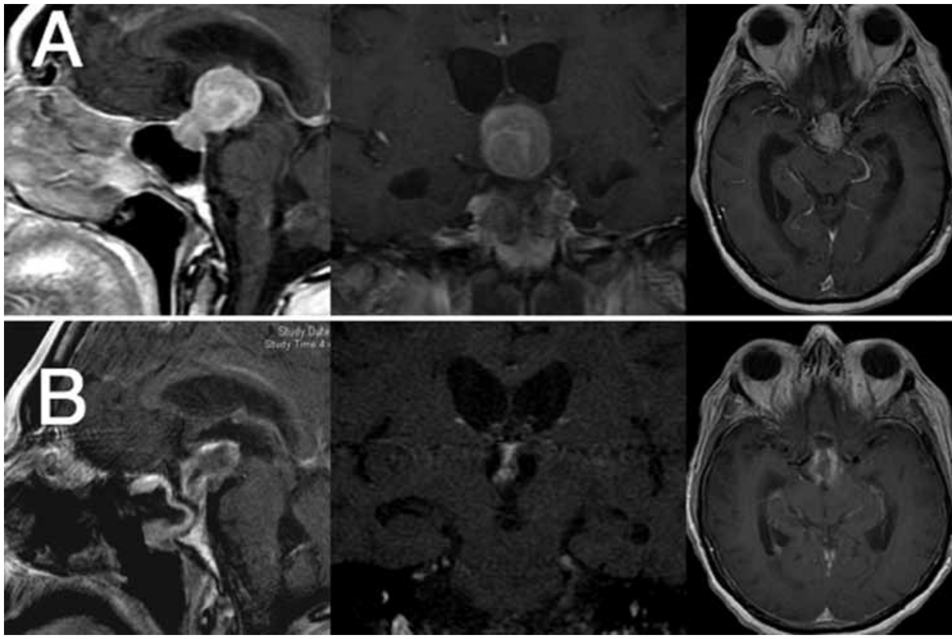


Fig. 4. Case 3. **A:** Preoperative sagittal, coronal, and axial T1-weighted MR images showing a large expansive and destructive mass extending into the sphenoid sinus, sellar and suprasellar area. **B:** Postoperative T1-weighted MR images confirming subtotal resection of the lesion.

tumors that are fibrous and avascular such as chordomas and macroadenomas. Bimanual suction is excellent for soft tumors, but once tumors become fibrous, this method often is not adequate. The NICO Myriad fills gaps in existing instrumentation.

The cost of the NICO Myriad is not insubstantial since there is a fixed cost for the main unit and additional costs for each disposable handpiece. We have found the NICO Myriad to be only useful for a small percentage of our cases, roughly 20%. However, for the cases in which the device was used, its use was thought to be almost essential to obtain a complete resection in a reasonable time period. For this reason, we feel that the NICO Myriad is worth the cost, even though it is only used in a subset of our cases. Whether the NICO Myriad leads to significant increases in extent of resection or survival is not known and would require a randomized trial. Such a trial will likely never be done, since it has not even been performed to justify the multimillion dollar acquisition of intraoperative MR imagers.

## Conclusions

The NICO Myriad tissue removal system is a safe, easy to use, and effective tool when used for internal debulking and extracapsular dissection of nonvascularized tumors that are too firm for bimanual suction or blunt ring curette dissection. It is particularly useful when working through a deep and narrow corridor such as is encountered in endoscopic endonasal skull base surgery.

### Disclosure

The authors report no conflict of interest concerning the material or methods used in this study or the findings specified in this paper. None of the authors has any financial interest in any device discussed in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Garcia-Navarro, Guerrero-Maldonado, Schwartz. Acquisition of data: Garcia-Navarro, Lancman. Analysis and interpretation of data: Garcia-Navarro, Guerrero-Maldonado. Drafting the article: Garcia-Navarro, Lancman. Critically revising the article: Anand, Schwartz. Reviewed final version of the manuscript and approved it for submission: all authors. Administrative/technical/material support: Garcia-Navarro, Lancman. Study supervision: Anand, Schwartz.

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*Supplemental online information:*

Video: http://mfile.akamai.com/21490/wmv/digitalwbc.download.akamai.com/21492/wm.digitalsource-na-regional/focus10-302.asx (Media Player).

http://mfile.akamai.com/21488/mov/digitalwbc.download.akamai.com/21492/qt.digitalsource-global/focus10-302.mov (Quicktime).

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# Surgical nuances for removal of retrochiasmatic craniopharyngioma via the endoscopic endonasal extended transsphenoidal transplanum transtuberculum approach

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Retrochiasmatic craniopharyngiomas are challenging tumors to remove given their deep location and proximity to critical neurovascular structures. Complete surgical removal offers the best chance of cure and prevention of recurrence. The endoscopic endonasal extended transsphenoidal approach offers direct midline access to the retrochiasmatic space through a transplanum transtuberculum corridor. Excellent visualization of the undersurface of the optic chiasm and hypothalamus can be obtained to facilitate bimanual extracapsular dissection to permit complete removal of these formidable tumors. In this report the authors review the endoscopic endonasal extended transsphenoidal approach, with specific emphasis on technical operative nuances in removing retrochiasmatic craniopharyngiomas. An illustrative intraoperative video demonstrating the technique is also presented. *(DOI: 10.3171/2011.1.FOCUS10297)*

**Key Words** • **endoscopic endonasal approach** • **skull base** • **extended transsphenoidal approach** • **transplanum transtuberculum** • **retrochiasmatic craniopharyngioma**

Craniopharyngiomas in the retrochiasmatic space are challenging tumors to remove surgically because of their anatomical location and proximity to critical neurovascular structures. They represent approximately 11%–46%[3,24,30,42,54,55] of all craniopharyngiomas, and are associated with a high rate of surgery-related morbidity and mortality as well as incomplete removal resulting in higher recurrence rates.[21,46,48,54] Retrochiasmatic craniopharyngiomas are thought to arise from a supradiaphragmatic origin,[55] and are therefore often situated behind the optic chiasm and can extend superiorly into the third ventricle and inferiorly into the interpeduncular cistern and retrosellar region.[21,49,54] Various transcranial surgical approaches to this region include the transbasal subfrontal, frontobasal interhemispheric, pterional, orbitopterional, orbitozygomatic, and petrosal approach.[1,2,16,20–22,27,29,43,45,51,52,54,57] Opening the lamina terminalis is often necessary to expose most retrochiasmatic craniopharyngiomas when using the subfrontal, interhemispheric, or transsylvian routes.[8,16,43,45,48] Alternatively, the transnasal route via the extended transsphenoidal approach offers a direct trajectory to the retrochiasmatic space and third ventricle, with excellent visualization of the undersurface of the optic chiasm and the interpeduncular cistern.[14,22,23] This route has the advantage of avoiding brain retraction and the risk of cerebral edema that can be associated with a transcranial approach.

The transsphenoidal microsurgical approach has traditionally been reserved for subdiaphragmatic craniopharyngiomas that are primarily intrasellar or intrasellar with suprasellar extension.[39–41,44,46] The advent of the extended transsphenoidal microsurgical approach as described by

*Abbreviation used in this paper:* ON = optic nerve.

Weiss,[56] which involves removing the tuberculum sellae and planum sphenoidale, has allowed surgeons to access suprasellar supradiaphragmatic craniopharyngiomas with normal-sized sellas.[13–15,18,23,34] More recently, the endoscope has played an increasing role in the surgical removal of craniopharyngioma,[4,5,11–15,18,19,22,25,26,31,32,34,35,37,38,56] and several authors have reported a purely endonasal endoscopic technique with favorable results comparable to microsurgical series.[12,25,32,38] However, only a few reports specifically address retrochiasmatic craniopharyngiomas resected using the endoscopic endonasal approach.[23]

The endoscopic endonasal extended transsphenoidal approach provides a direct midline exposure for access to retrochiasmatic craniopharyngiomas. This purely endonasal endoscopic technique offers excellent visualization of the retrochiasmatic region and allows for 2-handed tumor dissection off of the undersurface of the optic chiasm and hypothalamus by using microsurgical principles. We have adopted this technique as described by Kassam et al.,[35] Cappabianca et al.,[6] and Cavallo et al.[10] In this report, we review our surgical technique and describe the operative nuances for removal of retrochiasmatic craniopharyngiomas via the endoscopic endonasal extended transsphenoidal (transplanum transtuberculum) approach. We also present an illustrative intraoperative video demonstrating the technique (Video 1).

## Surgical Technique

*Patient Positioning*

After induction of general anesthesia, the endotracheal tube is secured to the left side of the patient. Although a lumbar drain can be placed at this time for temporary postoperative CSF diversion, we prefer not to use postoperative lumbar drainage because of potential complications arising from intracranial hypotension. The patient is placed supine on the operating table with the head fixed in a 3-point Mayfield head holder. The bed is slightly reflexed to keep the head slightly elevated above the heart to facilitate venous return. The head is slightly flexed toward the left shoulder and slightly rotated toward the right to enhance the surgeon's comfort in accessing the nose from the patient's right side. The head is also slightly extended to facilitate access to the anterior skull base. Frameless stereotactic imaging guidance is used for intraoperative navigation. This helps guide the extent of bone removal from the planum sphenoidale to gain an adequate trajectory toward the suprasellar target. The nose and nostrils are prepared with betadine and the nasal cavity is packed with Afrin-soaked pledgets. The thigh is also prepared for harvest of autologous fascia lata for dural repair and reconstruction. Intravenous antibiotics and 10 mg of dexamethasone are administered prior to incision.

*Endoscopic Endonasal Transsphenoidal Approach*

In our center we use a team approach, with a skull base neurosurgeon (J.K.L.) and an otolaryngologist specializing in rhinology, sinus, and endoscopic skull base surgery (J.A.E.). With both surgeons working together simultaneously, a 3- to 4-handed binostril technique is used without a traditional nasal speculum. The initial endonasal exposure to the sphenoid sinus is performed primarily by the otolaryngologist, who uses a 4-mm-diameter, 18-cm-long, 30° endoscope (Karl Storz). We prefer to start the exposure and resection with a 30° endoscope because it has the versatility to allow us to accomplish the same degree of exposure as with a 0° endoscope, but with the added benefits of additional angled viewing capabilities around corners, without repeatedly interchanging the endoscopes. The tail and anterosuperior attachment of the middle turbinates as well as the nasal septum are infiltrated with 1% lidocaine with epinephrine (1:100,000 dilution). Both middle and inferior turbinates are mobilized laterally. In some cases, the right middle turbinate can be removed, if necessary, to allow more room for multiple instruments in the right nostril. The sphenoid ostia are identified bilaterally, and a wide sphenoidotomy and posterior ethmoidectomy are performed with a microdebrider and Kerrison rongeurs.

At this juncture, we prefer to harvest a pedicled, vascularized, nasoseptal flap, which is rotated inferiorly into the nasopharynx. Further panoramic exposure of the skull base by maximizing the sphenoidotomy, posterior ethmoidectomy, and posterior septectomy can be continued while protecting the vascular pedicle to the nasoseptal flap. A posterior ethmoidectomy is performed with a microdebrider so that adequate exposure of the planum sphenoidale is obtained without any obstructive overhang of tissue. It is important to recognize the presence of an Onodi cell, a posterior ethmoid cell that is positioned superolateral to the sphenoid sinus, because the ON and carotid artery may often course through the lateral aspect of that cell. The posterior septectomy (approximately 1.5–2 cm) allows triangulation of surgical instruments through both nostrils so that bimanual dissection can be performed.

*Transplanum Transtuberculum Exposure (Extended Transsphenoidal)*

At this juncture, the otolaryngologist and neurosurgeon work simultaneously using a 3- to 4-handed binostril technique for the remainder of the operation. The otolaryngologist provides dynamic guidance and optimal visualization of the surgical target, with the endoscope primarily positioned in the right nostril. We do not use the endoscope holder, and prefer dynamic movements of the endoscope to facilitate depth perception of the anatomical target. The neurosurgeon uses continuous bimanual microsurgical technique, with a suction device primarily in the left hand inserted into the right nostril, and a drill, dissector, scissors, bipolar device, or tissue aspirator in the right hand inserted into the left nostril.

During the bone drilling and removal, we prefer to use a double-barrel suction-irrigating instrument in the right nostril. The self-irrigating system keeps the surgical field clear of bone dust during bone drilling, and also cools the drill tip from overheating. The sphenoidotomy is maximally widened with a high-speed diamond drill so that there is no bony overhang inhibiting the surgical freedom of the instrument (maneuverability) and no obstruction in the line of sight to the transplanum transtuberculum target. The bone over the sella turcica, tuberculum sellae, and planum sphenoidale is carefully removed. It is important to identify the medial opticocarotid recess, which is an indentation in the bone that is formed at the medial junction of the parasellar carotid canal and the optic canal. This recess represents the pneumatization of the middle clinoid and lateral aspects of the tuberculum sellae as viewed from the endonasal perspective.[35] The tuberculum strut along with both medial opticocarotid recesses are carefully thinned down to eggshell thickness with a high-speed diamond drill, with copious irrigation. Care is taken to avoid thermal injury to the ON. After the bone has been adequately thinned to eggshell thickness, the remaining tuberculum strut is removed with an up-angled 5–0 curette. By removing the medial opticocarotid recesses, the medial aspect of the optic canals are unroofed, which facilitates exposure of the ONs and paraclinoid carotid arteries in the opticocarotid cistern.[35] Venous bleeding from the cavernous and intercavernous sinuses can be readily controlled with Gelfoam or Surgiflo (Ethicon, Inc.).

*Tumor Resection*

We prefer to open the dura mater in a transdiaphragmatic fashion similar to the technique described by Weiss.[56] A size 15 blade is used to make a cruciate incision over the sellar dura, and a second horizontal incision is made in the dura of the planum sphenoidale above the intercavernous sinus. The intercavernous sinus is coagulated with a pistol-grip endoscopic bipolar device, and subsequently divided with scissors to obtain direct access to the suprasellar cistern. Care is taken to identify the pituitary gland and stalk, to preserve it whenever possible. Kassam et al.[35] have classified craniopharyngiomas based on the anatomical relationship of the tumor and the infundibulum, as follows: Type I, preinfundibular; Type II, transinfundibular; Type III, retroinfundibular; and Type IV, intraventricular. Although the location of the tumor in relation to the stalk can sometimes be predicted on preoperative MR imaging, larger craniopharyngiomas can obscure the location of the stalk, and the only way to confirm the location is at the time of surgery.[50] In cases of Type II transinfundibular craniopharyngiomas, the tumor expands and widens the stalk as it grows. In these cases, anatomical preservation of the stalk is difficult to achieve, perhaps at the cost of incomplete tumor removal. We therefore agree with Oldfield[47] that if the difference in complete and incomplete removal is based on anatomical preservation of the pituitary stalk (the preservation of which does not always retain pituitary function), it is better to choose complete tumor removal at the cost of sacrificing the stalk and accepting hormone replacement therapy. Therefore, in cases of Type II transinfundibular craniopharyngiomas, we prefer to perform a low stalk section to achieve a more aggressive removal of the tumor.

By using bimanual microsurgical dissection techniques, the tumor capsule in relation to the optic chiasm and ONs is identified. In retrochiasmatic craniopharyngiomas, the tumor is located underneath and posterior to the optic chiasm. It can often be adherent to the undersurface of the optic apparatus and hypothalamus, with tumor extension superiorly into the third ventricle and posteriorly into the interpeduncular fossa and retrosellar space. The anterior communicating artery complex is located superior to the optic chiasm and is therefore protected from the plane of dissection in retrochiasmatic craniopharyngiomas. A 30° endoscope allows a direct "looking-up" view of the retrochiasmatic space for extracapsular dissection. When 3–4 instruments are used at deep intradural targets, the 2 surgeons are often "fighting for space" with their instruments. We therefore recommend placing the endoscope at the 6 o'clock position, with the suction placed in the 12 o'clock position in the right nostril when using the 30° endoscope to look up into the retrochiasmatic space. The neurosurgeon is therefore working "above" the endoscope while maintaining the optimal surgical exposure. When using a 0° endoscope, we prefer to do the opposite and place the endoscope at the 12 o'clock and the suction instrument at the 6 o'clock position.

In larger tumors, initial debulking of solid components and/or aspiration of cystic fluid allows for decompression of the tumor capsule. Once the tumor is adequately debulked and decompressed, extracapsular dissection of the tumor capsule away from the optic chiasm and hypothalamus is performed with careful bimanual microdissection. Care is taken not to amputate the tumor capsule prematurely, so that enough tumor capsule serves as a "handle" to provide countertraction for extracapsular dissection. It is important to identify the double arachnoid layer and to distinguish the tumor arachnoidal plane from the cisternal arachnoid plane, if possible. The optimal plane of safe dissection is between the tumor capsule and the tumor arachnoid, not the cisternal arachnoid plane.[43] In most virgin cases, the Liliequist membrane is intact and serves as a protective barrier for the basilar artery, posterior cerebral arteries, and $P_1$ perforating vessels.[7,9] Once the tumor capsule is dissected free from the undersurface of the optic chiasm, hypothalamus, and surrounding vascular structures, the remaining tumor capsule can be delivered. If the floor of the third ventricle is open, a 30° and 70° endoscope can be used to look inside the walls of the third ventricle to inspect for residual tumor.

*Closure and Skull Base Reconstruction*

Closure is of critical importance in preventing a postoperative CSF leak. We prefer to place an initial autologous fascia lata graft harvested just slightly larger than the dural defect. The fascia lata graft is placed intradurally as an underlay graft, with its edges tucked underneath the dural edges. Several pieces of Surgicel are placed over the bone defect to hold the fascia graft in place temporarily. The vascularized nasoseptal flap is then rotated superiorly to cover the dural closure and bony skull base defect. Care is taken to ensure that the edges of the nasoseptal flap are in contact with the bone. A thin layer of DuraSeal (Covidien) or Tisseel (Baxter Healthcare Corp.) fibrin glue is spread over the nasoseptal flap, followed by gentamicin-soaked Gelfoam pledgets to buttress the flap repair. A Merocel (Medtronic Xomed) nasal pack is then placed in the nasal cavity to bolster the Gelfoam layer, and is left in place for approximately 10 days. The patient is maintained on antibiotics until the packs are removed. Because the patient is already in a CSF hypovolemic state at the end of surgery, we do not use postoperative lumbar drainage to avoid complications of CSF hypotension. Absence of a lumbar drain allows the patient to recover quicker and mobilize sooner, thus avoiding thromboembolic and pulmonary complications.

## Illustrative Cases

*Case 1*

This 53-year-old woman presented with worsening headaches and visual loss. Visual acuity was 20/60 bilaterally, with bitemporal hemianopia. Admission MR imaging studies demonstrated a purely suprasellar, transinfundibular retrochiasmatic craniopharyngioma with optic chiasm compression (Fig. 1). A transplanum transtuberculum endoscopic endonasal extended transsphenoidal approach was used to remove the tumor. Careful bimanual extracapsular dissection freed the adherent tumor from the hypothalamus (Fig. 2). Because the tumor had infiltrated and expanded the pituitary stalk (Type II transinfundibular), the stalk could not be preserved and was, therefore, divided to allow gross-total removal of the tumor. Inspection of the resection cavity with a 30° angled endoscope allowed excellent visualization of the entrance into the third ventricle and the basilar artery complex. Postoperatively, her visual acuity improved to 20/20, with resolution of bitemporal hemianopia. Hormone replacement therapy was initiated because of postoperative panhypopituitarism and diabetes insipidus. There was no CSF leakage.

*Case 2*

This 52-year-old woman presented with progressive visual loss and bitemporal hemianopia. Her visual acuity was 20/40 in the right eye and 20/200 in the left eye. Admission MR imaging studies demonstrated a cystic intrasellar and suprasellar retrochiasmatic craniopharyngioma exerting significant compression on the ONs and optic chiasm (Fig. 3). A transplanum transtuberculum endoscopic endonasal transsphenoidal approach (Video 1) was performed using 3D endoscopy (Visionsense, Ltd.).

**Video 1.** Intraoperative video showing removal of a retrochiasmatic craniopharyngioma by using the endoscopic endonasal extended transsphenoidal approach (Case 2). Click here to view with Windows Media Player. Click here to view with Quicktime.

The tumor capsule was very adherent to the undersurface of the optic chiasm and left ON (Fig. 4). The tumor was noted to be a Type II transinfundibular variant intraoperatively, and a low stalk section was performed to release and deliver the tumor. A near-total resection was performed, with a small microscopic remnant of calcified capsule that was adherent to the undersurface of the left ON. The postoperative visual examination showed improvement, and the patient was maintained on hormone replacement therapy for panhypopituitarism and diabetes insipidus. There was no postoperative CSF leakage.

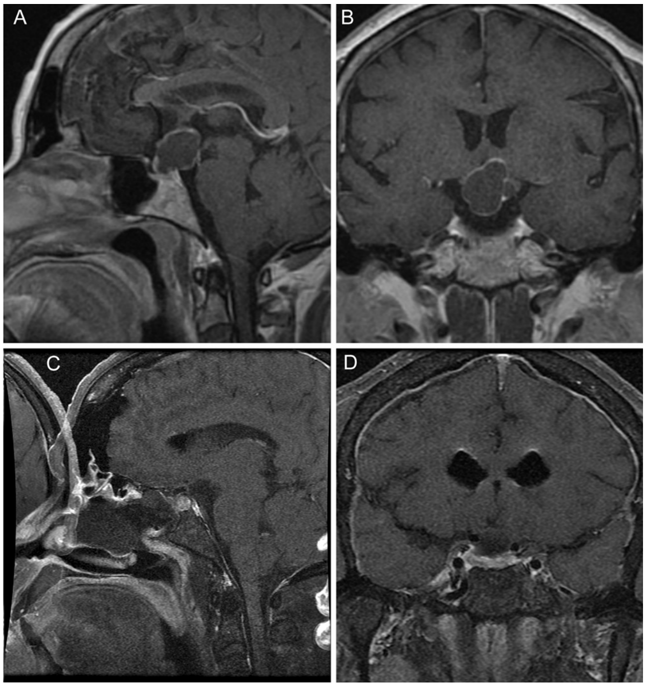


**Fig. 1.** Case 1. Preoperative sagittal **(A)** and coronal **(B)** T1-weighted post-Gd MR imaging studies demonstrating a transinfundibular retrochiasmatic craniopharyngioma with optic compression. Postoperative sagittal **(C)** and coronal **(D)** T1-weighted post-Gd MR imaging studies showing gross-total resection of the tumor.

## Discussion

*Surgical Approaches for Retrochiasmatic Craniopharyngioma*

The surgical removal of retrochiasmatic craniopharyngiomas presents a formidable challenge because of their deep location and intimate involvement with critical neurovascular structures. When a transcranial approach is used, such as a midline transbasal subfrontal, bifrontal interhemispheric, pterional, orbitopterional, supraorbital, or orbitozygomatic approach, the conventional operative corridors through the interoptic and opticocarotid cisterns allow limited exposure and inadequate visualization of the infra- and retrochiasmatic regions.[2,54] Because these tumors are hidden behind an anteriorly displaced or prefixed chiasm, it is often necessary to open the lamina terminalis to access these lesions in the retrochiasmatic space. The translamina terminalis exposure is an effective route in experienced hands; however, the undersurface of the optic chiasm and ONs remains a blind spot from the transcranial view. Al-Mefty et al.[1] and Hakuba et al.[29] have advocated the posterior petrosal approach for retrochiasmatic craniopharyngiomas because of its upward projection to dissect the upper pole of the tumor with direct visualization of the hypothalamus and pituitary stalk. However, this approach has the disadvantages of prolonged temporal lobe retraction, potential injury to the vein of Labbé, and loss of midline orientation with a lateral projection.

The transnasal transsphenoidal route provides a direct midline approach to the suprasellar region without any brain retraction.[17,18] In the past, this approach was generally reserved for craniopharyngiomas that were primarily subdiaphragmatic in origin, with an enlarged sella. However, with the refinement of the extended trans-

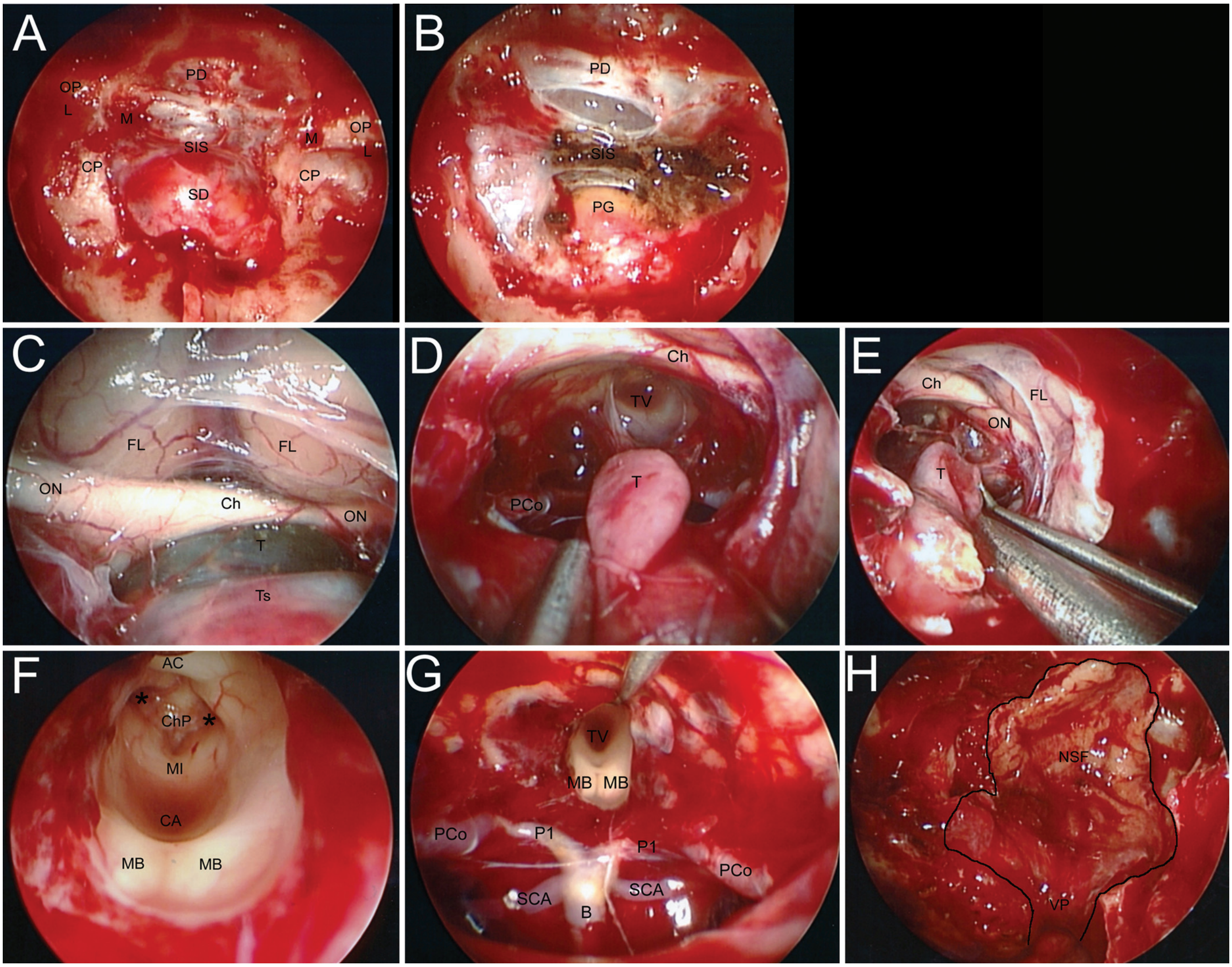


Fig. 2. Case 1. Intraoperative endoscopic photographs. **A:** Endoscopic view of the skull base after removal of bone from the planum sphenoidale, tuberculum sellae, and sella turcica. The following landmarks are important to identify for proper anatomical orientation: dura overlying the planum sphenoidale (PD); the superior intercavernous sinus (SIS), which is deep to the tuberculum sellae; the sellar dura (SD); the medial opticocarotid recess (M); the lateral opticocarotid recess (L); the carotid protuberance (CP) indicating the parasellar carotid artery; and the optic protuberance (OP) indicating the ON. **B:** The planum dura and sellar dura have been opened, allowing visualization of the pituitary gland (PG). At this juncture, the superior intercavernous sinus is thoroughly coagulated and subsequently divided to provide access to the suprasellar space. **C:** Endoscopic view of the frontal lobes (FL), the optic chiasm (Ch), and ONs. The retrochiasmatic tumor (T) is adherent to the undersurface of the optic chiasm and hypothalamus. The transinfundibular tumor is also seen expanding and infiltrating the stalk. **D and E:** Extracapsular tumor dissection is performed using a bimanual microsurgical technique. The tumor is carefully dissected away from the right posterior communicating artery (PCo). Once the tumor has been dissected away from the optic chiasm and hypothalamus, the entrance into the third ventricle (TV) can be visualized. **F:** Endoscopic endonasal view of the third ventricle shows the anterior commissure (AC), foramen of Monroe (*), choroid plexus (ChP), massa intermedia (MI), cerebral aqueduct (CA), and mammillary bodies (MB). **G:** Following tumor resection the following neurovascular structures of the interpeduncular and prepontine cistern can be visualized: the basilar artery (B); superior cerebellar arteries (SCA); the posterior cerebral arteries (P1); and the posterior communicating arteries. **H:** View of the nasoseptal flap (NSF; outlined by *black line*) and its vascular pedicle (VP) that covers the entirety of the dural closure and skull base defect. Ts = tumor infiltrating the stalk.

sphenoidal approach that involves creating a transplanum transtuberculum corridor through the anterior skull base, purely suprasellar tumors of supradiaphragmatic origin became accessible with a normal-sized sella. Successful tumor removal has been reported when using the speculum-based microsurgical extended transsphenoidal approach.[13,14,18,22,34,56] However, visualization at the highest magnification of the microscope limits the amount of illumination of the surgical target. The surgical field of view is limited by the corridor and aperture of the distal end of the speculum. Surgical freedom (that is, the range of instrument maneuverability) and line of sight are also compromised with a deep and narrow working channel formed by the blades of the nasal speculum.

The endoscope offers the advantages of better illumination of the surgical target, with a much wider field

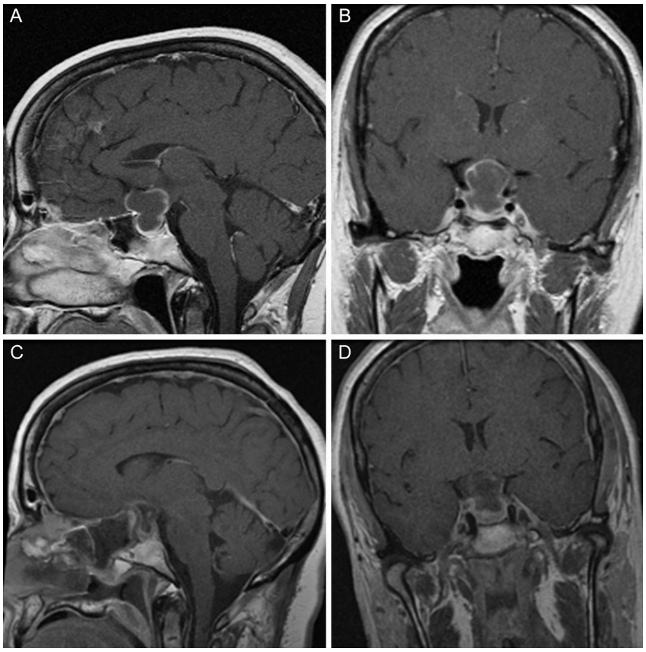


**Fig. 3.** Case 2. Preoperative sagittal **(A)** and coronal **(B)** T1-weighted post-Gd MR imaging studies demonstrating a retrochiasmatic craniopharyngioma with an intrasellar component resulting in optic compression. A transinfundibular type tumor was found at surgery. Postoperative sagittal **(C)** and coronal **(D)** T1-weighted post-Gd MR imaging studies showing near-total resection of the tumor. A small calcified remnant was adherent to the undersurface of the left ON.

of view. A panoramic view from the planum sphenoidale to the clival recess and from one medial opticocarotid recess to the other can be obtained. Unlike the microscope, the endoscope allows high magnification of the surgical target without loss of illumination by bringing the light source and lens directly up to the target. The purely endonasal endoscopic approach allows a direct view of the undersurface of the optic chiasm and the retrochiasmatic region because the approach originates below the chiasm. Direct extracapsular dissection of the tumor off of the visual apparatus, hypothalamus, pituitary stalk, and perforating vessels can be performed with bimanual microsurgical technique. The use of angled endoscopes allows visualization of lesions "around corners," which can then be removed under direct visualization. Lesions extending into the third ventricle and interpeduncular space can be easily accessed and visualized. By using a binostril technique, there is a larger range of motion for instrument maneuverability that was previously encumbered by the nasal speculum.[17,18,33] This working space is largely created by maximizing the sphenoidotomy, posterior ethmoidectomy, posterior septectomy, and sometimes a middle turbinectomy.

One of the major criticisms of endonasal surgery for craniopharyngiomas and other intradural tumors is the rate of CSF leakage. This has been significantly reduced by the application of the vascularized nasoseptal flap.[28,36] The flap tissue is robust and provides excellent coverage of skull base defects. The major advantage is that the tissue is vascularized to optimize healing and prevent CSF leaks.

*Limitations of the Endoscopic Endonasal Approach*

The endoscopic endonasal approach becomes more difficult and technically demanding in tumors that extend laterally into the sylvian fissure with intimate involvement of the middle cerebral artery and its perforating vessels. This area is difficult to access with angled instruments, and it is also difficult to achieve adequate control in the event of neurovascular injury. In cases with lateral extension, we prefer to choose a transcranial approach, such as an extended frontotemporal orbitozygomatic approach that allows transsylvian and translamina terminalis access. For Type IV purely intraventricular craniopharyngiomas, we prefer the transbasal subfrontal translamina terminalis approach.[43]

A conchal nonpneumatized sphenoid sinus can make the endonasal approach more difficult because there is a lack of natural bony landmarks as seen in a well-aerated sinus.[12] Creating the working corridor can be more laborious. In this setting, neuronavigation, which can help confirm surgical landmarks, is indispensable. Although an endoscopic endonasal approach can still be safely performed in experienced hands, one may consider a transcranial approach depending on the size, location, and consistency (solid vs cystic) of the tumor.

The 2D view provided by the endoscope has been considered a limitation compared with the 3D view afforded by the microscope.[33] We would argue, however, that the dynamic mobility of the endoscope allows the lens to move closer and further away from the target, conveying a sense of depth perception. Placement of the suction in the clival recess also provides tactile feedback to the operating surgeon to give a sense of depth as well. The panoramic view afforded by the endoscope also assists in defining 3D relationships. The availability of recently developed 3D endoscopes (Visionsense, Ltd.) has now greatly improved subjective depth perception for the operating surgeon.[53] These endoscopes are based on dual channel technology that incorporates information from 2 distinct perspectives to render a single 3D view, similar to human vision. A recent report of a study performed using the 3D endoscope for pituitary tumor removal demonstrated subjective improvement in depth perception without increased complications or operating time.[53]

## Conclusions

The endoscopic endonasal extended transsphenoidal transplanum transtuberculum approach provides direct midline access to retrochiasmatic craniopharyngiomas. Excellent visualization of the undersurface of the optic chiasm and hypothalamus can be obtained to facilitate bimanual extracapsular dissection, to permit complete removal of these formidable tumors.

#### Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Liu, Eloy. Acquisition

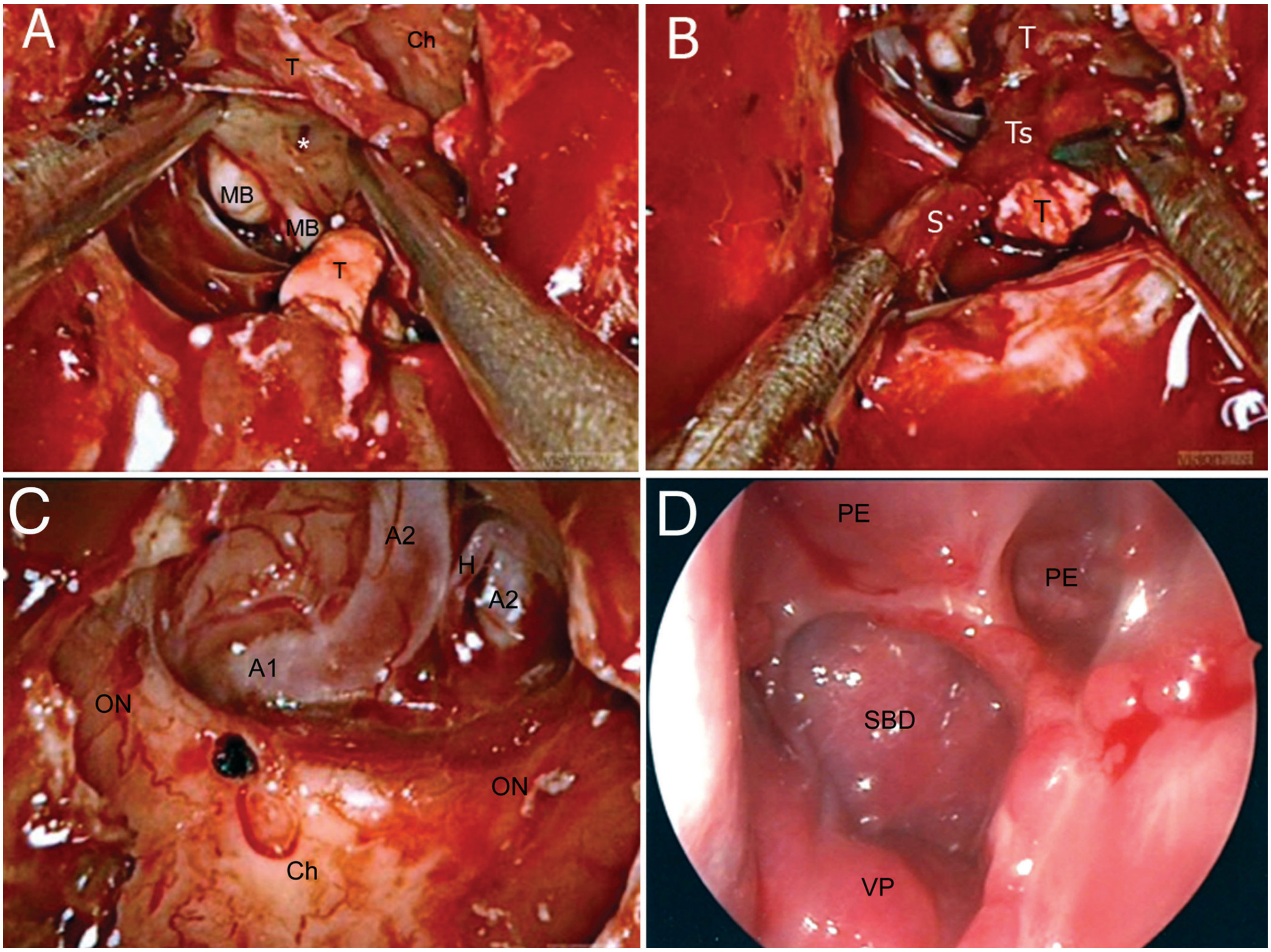


Fig. 4. Case 2. Intraoperative photographs taken through a 3D endoscope. **A and B:** Endoscopic view of extracapsular tumor dissection off of the undersurface of the optic chiasm using bimanual microsurgical technique. The mammillary bodies and entrance into the third ventricle (*) are identified. This tumor was noted to be a Type II transinfundibular craniopharyngioma with infiltration and expansion of the pituitary stalk (S). A low division of the stalk was performed to allow near-total removal of the tumor. A small calcified remnant was adherent to the undersurface of the left ON. **C:** Endoscopic view of the undersurface of the optic chiasm and ONs after tumor removal. The $A_1$ and $A_2$ segments of the anterior cerebral arteries and the recurrent artery of Heubner (H) are identified. **D:** Endoscopic view of the skull base repair with a nasoseptal flap at 2 months after surgery demonstrates a well-healed nasoseptal flap and vascular pedicle with reconstitution of the mucosal lining overlying the skull base defect (SBD) and the posterior ethmoids (PE). See Fig. 2 for definitions of abbreviations.

of data: all authors. Analysis and interpretation of data: Liu, Christiano, Eloy. Drafting the article: all authors. Critically revising the article: all authors. Reviewed final version of the manuscript and approved it for submission: Liu. Administrative/technical/material support: Patel. Study supervision: Liu.

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http://mfile.akamai.com/21488/mov/digitalwbc.download.akamai.com/21492/qt.digitalsource-global/focus10-297.mov (Quicktime).

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See the corresponding editorial in this issue (E16).

**Neurosurg Focus 30 (4):**E15, 2011

# Thoracoscopic discectomy and instrumented fusion using a minimally invasive plate system: surgical technique and early clinical outcome

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*Object.* The use of minimally invasive noninstrumented fusions has increased as thoracoscopic approaches to the spine have evolved. The addition of instrumentation is infrequent, in part because of the lack of a minimally invasive implant system. The authors describe a technique for thoracoscopic plating after discectomy and report early clinical outcomes.

*Methods.* After a standard endoscopic discectomy and partial corpectomy and before exposure of the ventral thecal sac, the authors implanted a polyaxial screw and clamping element under fluoroscopic guidance. Reconstruction involves placement of autograft in the defect and subsequent placement of the remainder of the screw/plate construct with 2 screws per vertebral level.

*Results.* Twenty-five patients underwent thoracoscopic and thoracoscopy-assisted discectomies and fusion in which the aforementioned plate system was used. Of 19 patients presenting with pain, 10 had 6-month clinical follow-up with a greater than 50% reduction in visual analog scale score, which continued to improve up to 2 years postoperatively. There were 3 cases of pneumonia, 3 CSF leaks, 1 chyle leak, and 1 death due to a massive pulmonary embolus on the 1st postoperative day.

*Conclusions.* The authors conclude that thoracoscopic discectomy and plate-instrumented fusion can be achieved with acceptable results and morbidity. Further studies should evaluate the role of instrumented fusions after thoracoscopic discectomy in larger groups of patients and during a longer follow-up period.

*(DOI: 10.3171/2011.1.FOCUS10309)*

**Key Words** • **thoracic discectomy** • **thoracic fusion** • **thoracoscopic technique** • **minimally invasive surgery**

Although thoracic disc herniation is a common finding on MR imaging in asymptomatic individuals, it accounts for less than 1% of clinically significant herniated discs and less than 2% of surgical discectomies.[7,14,19] A lower incidence of disc herniation in the thoracic spine than in the cervical and lumbar regions is attributed to the coupling of the thoracic spine to the rib cage and the costovertebral articulations, which increase spinal stability and minimize spinal flexion. Despite their rarity, symptomatic thoracic herniated discs can result in a range of neurological symptoms, including radiculopathy and axial pain as well as myelopathy. Most patients can undergo conservative management, but in patients in whom conservative therapy fails or those who present with progressive myelopathy, surgery is advocated. The operative approach to the thoracic disc has evolved over the last several decades to enhance visualization while minimizing morbidity. Current options include various posterior, posterolateral, and anterior approaches, each suited for specific pathoanatomy and patient characteristics. More recently, with the introduction of endoscopic techniques, the anterior thoracic spine can now be accessed through a minimally invasive approach.

Biomechanical studies indicate that thoracic discectomy results in increased range of motion as well as significant perturbation of the neutral zone, indicating instability,[6] but the necessity of fusion with thoracic discectomy is still the subject of debate. Although the use of screw/plate instrumentation has been shown to decrease the pseudarthrosis rate and obviate the need for postoperative orthosis in other spinal regions,[8,9,12] this technique has been used infrequently in the thoracic spine. An additional deterrent to its use in thoracoscopic procedures has been the lack of a minimally invasive implant system.

The purpose of this study is to describe a minimally invasive surgical technique for thoracoscopic plating after discectomy, with fusion and early clinical outcomes.

*Abbreviations used in this paper:* EBL = estimated blood loss; LOS = length of stay; VAS = visual analog scale.

## Methods

Under an institutional review board–approved protocol, data were collected prospectively from April 2003 through September 2009 at the University of Utah to evaluate clinical outcomes after thoracoscopic discectomy and instrumented fusion using the MACS-TL plating system (Aesculap), a screw/plate construct that allows for 2 screws per vertebral level. The plate system gained US FDA approval in 2002, with an implant cost of approximately $6000 US. In all patients surgery was performed by one of two senior surgeons (R.I.A. and M.H.S.). Outcome data included operative time, blood loss, hospital LOS, complications, and postoperative pain.

### *Operative Technique*

Preoperative evaluation included plain radiography as well as thoracic MR and CT imaging to delineate the disc disease and the bony anatomy for placement of a screw/plate construct and interbody graft. The CT scan is also important to determine whether the disc is calcified and to indicate the position of the aorta in relationship to the spine. In addition to routine laboratory testing, an electrocardiogram and a chest radiograph should be obtained to evaluate for potential pleural fluid or other contraindicative lung conditions.

The patient is intubated using a double-lumen endotracheal tube to achieve single-lung ventilation for maximal surgical exposure. The patient is positioned as previously described by Amini et al.[2] Electrophysiological monitoring, including somatosensory evoked potentials and motor evoked potentials, is used during the procedure. A left-sided approach is preferred for access to the thoracolumbar junction because it avoids the liver, and a right-sided approach is preferred for the middle to upper thoracic spine to avoid the great vessels.[5] However, if the herniated disc is eccentric, the approach is on the side of the protrusion.

The technique used for a thoracoscopic discectomy and instrumented fusion is summarized below (Video 1).

**Video 1.** Video demonstrating a thoracoscopic discectomy and instrumented fusion technique. Click here to view with Windows Media Player. Click here to view with Quicktime.

The positioning and spinal exposure have been described in detail by Amini et al.[2] In brief, a lateral spine image is obtained fluoroscopically and used to identify landmarks and portal sites on the patient's skin. Counting the vertebral bodies and disc spaces identifies the appropriate level. More recently, we have also used a metallic marker that is placed preoperatively for identification of the correct level.[4] The working portal is positioned directly over the affected disc; the camera portal is positioned caudal to the working portal for lesions in the upper or middle thoracic spine or 2–3 intracostal spaces cranial to the lesion for thoracolumbar lesions. The suction/irrigation portal and retractor portal are both positioned ventral to the working portal and slightly cranial or caudal, respectively (Fig. 1). Because of the risk of inadvertent injuries during placement of the portals, the first portal is placed at the site farthest from the diaphragm by using a minithoracotomy technique. In all cases, the surgeon should be prepared for the potential of injury that would necessitate conversion to a full thoracotomy. After the endoscope has been introduced, the other portals are placed under direct visualization.

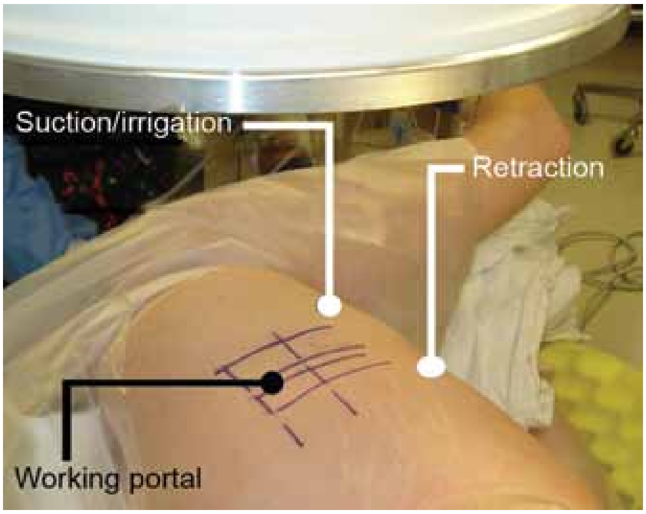


**Fig. 1.** Intraoperative photograph showing patient positioning and location of the portals.

The involved vertebral bodies and intervening disc space are identified using fluoroscopy, and the correct level of pathology is confirmed. A pleural flap is elevated, exposing the disc space and the cephalad and caudad vertebral bodies with their respective segmental arteries and veins, as well as the rib head overlying the disc space.

Once the vessels have been identified, coagulated or clipped, and cut, a standard endoscopic discectomy and partial corpectomy can be undertaken. First, the rib head is resected and kept as a source of graft for the fusion. The disc is then incised with an endoscopic knife and removed with rongeurs.

Prior to the exposure of the ventral thecal sac, fluoroscopy is used to insert a K-wire in either the proximal or distal vertebral body undergoing instrumentation. The MACS-TL polyaxial screw and clamping element is then placed over the K-wire under fluoroscopic guidance. This helps define the working area. Knowing the location of the posterior vertebral body at all times enhances safety and facilitates the operation.

Partial corpectomies are then performed with a Midas Rex drill equipped with a coarse diamond drill bit (Fig. 2 left). To access the ventral canal, a partial or complete removal of the caudal pedicle is performed. Once the bony removal is complete, the disc fragment is pulled into the defect using a combination of curettes and dissectors with care to not retract or pull on the thecal sac.

Reconstruction begins with the placement of structural and morselized rib autograft in the discectomy/partial corpectomy defect, filling the defect as completely as possible with the available graft material. The posterior screw in each vertebral body is placed over the K-wire using fluoroscopy and a specialized aiming device to ensure the screw is placed a safe distance from the posterior vertebral body wall to avoid canal penetration. The plate is sized using a caliper and then placed over the screw construct

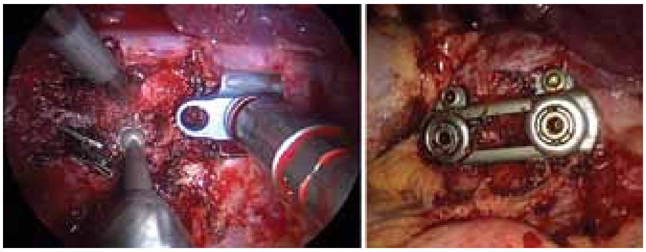

**Fig. 2.** **Left:** Endoscopic view showing partial corpectomy with a diamond bur. **Right:** Endoscopic view showing a screw/plate construct in its final position.

and secured with locking nuts (Fig. 2 right). Prior to plate placement, the working portal is removed and a speculum is introduced through the incision. The speculum allows for temporary dilation of the skin and soft tissue to provide access to the thoracic cavity for the plate (Fig. 3). The anterior screws are then placed convergently using an aiming device. Last, the locking screws are applied to secure the polyaxial mechanism. Before closure, a small chest tube is placed through one of the portal sites, and the lung is reinflated under direct endoscopic vision. The chest tube is usually removed on the 1st postoperative day, and a chest radiograph is obtained to rule out pneumothorax. Patients are mobilized immediately, and no postoperative orthoses are used. Patients return for postoperative follow-up visits at 1, 3, 6, 12, and 24 months.

## Results

Twenty-five patients underwent thoracoscopic discectomies and instrumented fusion in which the MACS-TL system was used, including 19 for degenerative thoracic disc herniation, 5 for traumatic disc disruption, and 1 for discitis. These 25 patients comprised the study population. The mean preoperative VAS pain score in 19 patients presenting with pain was 6 (median 7, range 1–10).

**Fig. 3.** Photograph of the instruments used for introducing the plate into the thoracic cavity.

Most of the patients had lower thoracic and thoracolumbar disc disease. A summary of patient demographic characteristics, side and level of disease, and operative variables including EBL, operative time, and complications is shown in Table 1.

The mean operative time was 337 minutes (range 154–672 minutes). The mean and median EBL levels were 505 and 275 ml, respectively. In patients without postoperative complications, the mean LOS was 4.75 days (range 3–14 days). In patients with complications (3 cases of pneumonia, 3 CSF leaks, and 1 chyle leak) the mean LOS was 16.5 days (range 3.3–43 days). The chyle leak was an unusual complication that has been described previously.[1] One patient died of a massive pulmonary embolus on the 1st postoperative day. In cases of CSF leaks, management involved intraoperative placement of fibrin glue and the initial postoperative placement of a chest tube for gravity drainage only, with early removal. The total perioperative complication rate in our series was 32%, slightly higher than the 21% complication rate reported by Anand and Reagan,[3] the largest reported series of thoracoscopic discectomies with and without fusion, but lower than the 42.3% complication rate reported by Watanabe et al.[20] in their evaluation of complication rates in endoscopic spinal surgery.

Among the 19 patients with pain symptoms, the mean VAS score improved by 33% at 1 month; a continued reduction to greater than 50% improvement was also seen at 6 months, and this was sustained at 2 years (Fig. 4). No patient required a reoperation for a symptomatic nonunion.

## Discussion

Unique anatomical and regional features of the thoracic spine have led surgeons to develop varied approaches to the operative management of thoracic disc herniations. With a small disease incidence and a plethora of procedures, the optimal operative management has been controversial, although recently some consensus has developed. In a frequently quoted paper, Bohlman and Zdeblick[5] advocated the use of an anterior approach for thoracic discectomy because it offers improved visualization of the thecal sac. Additionally, they advocated using fusion in which iliac crest allograft is combined with postoperative orthosis whenever the surgical approach necessitates significant bony decompression.[5] The authors of a recent review of the literature proposed an algorithm that advocates anterior approaches for central or centrolateral and calcified thoracic discs.[17] Thus, it appears that the use of an anterior approach as the optimal choice in most patients has developed some acceptance, but controversy remains regarding the necessity of adding a fusion. Furthermore, the safety and efficacy of adding screw/plate instrumentation to a thoracic discectomy and fusion have not been explored.

To investigate the biomechanics of thoracic discectomy and evaluate the need for fusion, Broc et al.[6] performed nondestructive flexibility testing on human

**TABLE 1: Summary of demographic data and operative variables***

| Case No. | Age (yrs), Sex | Side of Approach | Level of Disease | Pathology | EBL (ml) | Op Time (min) | LOS (days) | Complication |
|---|---|---|---|---|---|---|---|---|
| 1 | 47, M | rt | T6–7 | HNP | 700 | 360 | 4 | none |
| 2 | 47, M | lt | T10–11 | HNP | 500 | 345 | 7 | none |
| 3 | 45, F | lt | T9–10 | HNP | 100 | 240 | 3 | none |
| 4 | 48, F | lt | T12–L1 | HNP | 1300 | 359 | 4 | none |
| 5 | 58, M | rt | T6–7 | HNP | 650 | 364 | 6 | none |
| 6 | 47, F | lt | T10–11 | HNP | 600 | 290 | 4 | none |
| 7 | 43, M | lt | T10–11 | HNP | 1500 | 271 | 3 | none |
| 8 | 41, F | rt | T7–8 | HNP | 300 | 240 | 7 | none |
| 9 | 34, F | rt | T9–10 | HNP | 100 | 276 | 3.2 | none |
| 10 | 38, M | lt | T9–10 | trauma | 250 | 214 | 14 | none |
| 11 | 58, M | rt | T6–7 | HNP | 300 | 415 | 5.2 | none |
| 12 | 40, M | rt | T9–10 | HNP | 100 | 349 | 3.1 | none |
| 13 | 51, F | lt | T12–L1 | HNP | 1700 | 396 | 14 | chyle leak |
| 14 | 17, F | rt | T7–8 | trauma | 150 | 154 | 8 | pneumonia |
| 15 | 21, M | lt | T12–L1 | trauma | 200 | 235 | 43 | pneumonia |
| 16 | 56, M | lt | T11–12 | HNP | 900 | 333 | 10.6 | none |
| 17 | 57, F | lt | T8–9 | HNP | 1500 | 469 | 3.3 | CSF leak |
| 18 | 49, F | rt | T6–7 | HNP | 400 | 517 | 3.4 | none |
| 19 | 17, F | lt | T10–11 | trauma | 200 | 236 | 14 | pneumonia |
| 20 | 69, F | lt | T11–12 | trauma | 200 | 282 | 3 | none |
| 21 | 70, M | rt | T11–12 | infection | 100 | 216 | 3 | none |
| 22 | 56, F | rt | T3–4 | HNP | 50 | 402 | 3.7 | none |
| 23 | 36, M | rt | T8–9 | HNP | 250 | 396 | 3.3 | CSF leak |
| 24 | 25, M | rt | T7–8 | HNP | 150 | 388 | 1.5 | CSF leak; death due to massive pulmonary embolus |
| 25 | 43, F | rt | T5–6 | HNP | 250 | 672 | 4 | none |

* HNP = herniated nucleus pulposus.

cadaveric thoracic spines before and after microdiscectomy and found that, although the neutral zone, elastic zone, and range of motion increased significantly in all directions after discectomy, the magnitude of change was small. Additionally, there was no statistical difference in the instantaneous axis of rotation before and after discectomy. They concluded that thoracic microdiscectomy had small effects on the immediate mechanics and kinematics of the thoracic spine and did not overtly destabilize

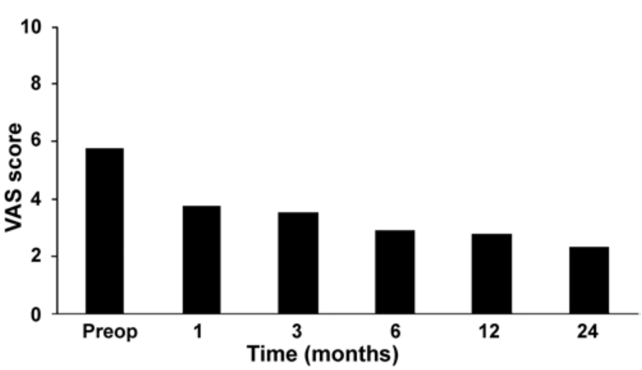


**Fig. 4.** Bar graph showing mean VAS scores preoperatively and at 1, 3, 6, and 12 months postoperatively.

the motion segments.[6] In contradistinction, Takeuchi et al.[18] reported results obtained in a canine spine model of thoracic discectomy that showed that the intervertebral disc regulates the stability of the thoracic spine in flexion-extension, lateral bending, and axial rotation. Moreover, the articulation of the rib head with the vertebral bodies provides stability to the thoracic spine in lateral bending and axial rotation. Unilateral resection of the rib head joint after partial discectomy produced significant coupled motions in lateral bending and axial rotation, resulting in a significant decrease in thoracic spinal stability and integrity.[18]

Despite biomechanical studies that suggest that thoracic discectomy may cause a decrease in spinal stability that could be improved by fusion, comparison of clinical outcomes of thoracic fusion and nonfusion after discectomy showed equivocal findings. In 1988, Otani et al.[14] reported on 23 patients treated surgically over a 16-year period for symptomatic thoracic disc herniation. They described a procedure consisting of total discectomy, intervertebral body fusion in which autogenous iliac bone was placed via an anterior approach, and postoperative immobilization with a plaster jacket for 10–12 weeks, which resulted in an excellent or good outcome in 79% of the cases and a fusion rate of 100% as assessed on radiography at 6-month follow-up. In 1994, Currier et al.[9] reported their case series of central or centrolateral disc herniation in 19 patients who underwent transthoracic discectomy and fusion, involving either autogenous rib graft or allograft. All patients were placed in thoracolumbosacral orthosis for 3 months postoperatively. Of the 17 patients available for follow-up, 12 had either excellent or good outcomes, with a 100% final fusion rate (1 patient had pseudarthrosis requiring posterior instrumentation).[9] Despite the positive results with their technique, these authors suggested the use of arthrodesis only if the decompression caused instability, such as when the decompression is extended to avoid compromising the collateral blood flow to the spinal cord in the neural foramina or to improve visualization. Anand and Regan[3] have discussed their experience using an endoscopic technique for thoracic discectomy and fusion. In their series of 100 patients, 40 patients with axial back pain and concordant discography underwent fusion with either autogenous rib graft or a BAK cage. Among patients who presented with a predominant component of axial pain, the Oswestry Disability Index (ODI) and VAS back pain scores in those in the discectomy/fusion group were compared with those in discectomy-alone group. Both groups showed a significant reduction in ODI and VAS scores, but there was no significant difference between the 2 groups, which were not randomized.[3] Our patients experienced similar long-term pain reduction (mean 24-month reduction 5.5 points). Furthermore, a significant portion of the reduction in VAS scores occurred early in our patients' postoperative course (mean 3-month reduction 4.25 points). This agrees with our clinical impression that these patients promptly return to work and to usual activities of daily living. In the absence of controlled studies, the decision to add a fusion to a thoracic discectomy relies on the surgeon's judgment of the clinical and intraoperative situation. Indeed, some authors advocate using the degree of back pain to guide operative decision making, stating that fusion should be reserved for patients presenting with a significant component of axial back pain.[3,10,12,14] A fusion may also be the treatment of choice to arrest any further motion at the level of a myelopathic spinal cord. In summary, clinical outcomes in the studies by Otani et al.,[14] Currier et al.,[9] and Anand and Regan,[3] as well as in the present cases, suggest both the safety and efficacy of transthoracic discectomy and fusion; however, the superiority of discectomy and fusion over discectomy alone remains to be proven clinically.

At present, the MACS-TL system is the only screw/plate construct for the anterior thoracic spine that has been designed to be introduced using endoscopy. It is a modular system that uses polyaxial screws to allow the clamping element to be placed flat on the vertebral bodies and stabilized. The plate is ultimately inserted in the clamping element and secured with locking nuts. The entire construct is not only low profile but is designed with no sharp edges, the presence of which could be dangerous in the thoracic cavity. Although benefits and drawbacks to using a minimally invasive thoracoscopic approach have been described in detail in previous publications,[2,7,8,11,13,15,16] there has been little discussion of the use of anterior screw/plate instrumentation to enhance fusion in the thoracic spine. In the current study, we performed 25 thoracoscopic and thoracoscopy-assisted discectomies using the MACS-TL plating system. All patients with follow-up reported a substantial and sustained clinical improvement postoperatively. Although the procedure is technically demanding with a steep learning curve, the plating system adds visual cues to the 2D image of an endoscopic approach because the initial placement of one of the posterior screws cranial and caudal to the disc space defines the working area and the location of the canal. In contrast to patients who undergo fusion without plate fixation, the patients in this cohort were mobilized without needing to wear a brace, which facilitates postoperative care and patient comfort. The patients reported a substantial and sustained clinical improvement postoperatively.

## Conclusions

To date, this is the only report detailing the efficacy and safety of adding screw/plate instrumentation to thoracic fusion after discectomy. Although fusion techniques involving cage systems or structural allo- and autograft techniques have been used after discectomy in patients who present with axial pain, no study to date has reported on the use of a plate system, which may not only confer more immediate stability to a fused segment, thereby decreasing postoperative pain, but may also obviate the need for postoperative orthosis. Our study shows that thoracic discectomy and fusion with plate fixation via a minimally invasive approach can be achieved with postoperative clinical improvement and minimal morbidity. Further studies are necessary to evaluate the role of plate-assisted fusions after thoracoscopic discectomy.

#### Disclosure

Dr. Schmidt serves as a consultant for Aesculap. The remaining authors report no other conflicts of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Schmidt, Apfelbaum. Acquisition of data: Bisson. Analysis and interpretation of data: Bisson. Drafting the article: Bisson. Critically revising the article: Schmidt, Jost, Apfelbaum. Reviewed final version of the manuscript and approved it for submission: all authors. Study supervision: Schmidt.

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*Supplemental online information:*

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See the corresponding article in this issue (E15).

Neurosurg Focus 30 (4):E16, 2011

# Editorial

## Thoracic discectomy and plating

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Although thoracic disc herniation is a rare disease accounting for less than 1% of clinically significant disc herniations, the high rates of morbidity and mortality associated with its treatment have been highlighted by numerous reports in the literature. In the earliest report of surgical treatment (laminectomy) of a herniated thoracic disc in 3 patients, Mixter and Barr[11] reported that 2 patients had complete paraplegia and 1 patient died. Subsequent reports of laminectomy for treatment of thoracic herniations repeatedly illustrated the high morbidity and mortality rates associated with laminectomy with an accumulated morbidity rate of 59% and mortality rate of 13%, as reported by Fessler and Sturgill[5] in their review of surgical complications in thoracic disc disease over a 60-year period.

The trepidation that arose due to complications associated laminectomy for thoracic disc herniation led to modified surgical approaches including posterolateral routes such as transpedicular, costotransversectomy, and lateral extracavitary approaches.[4,6,10,14–16] In addition, an anterolateral approach by the transthoracic route was adapted to improve visualization of the spinal canal to decrease the neurological morbidity rate associated with surgery of this disease.[10,17] Although there is no consensus on the most ideal surgical approach to thoracic disc herniation, except for avoidance of laminectomy, several clinical series have shown that the transthoracic approach and lateral extracavitary approaches, which allow for the most direct visualization of the spinal canal and cord, appear to have the lowest neurological morbidity rates.[5,10,17] However, these approaches are associated with other significant approach-related complications, including pain, blood loss, cardiopulmonary complications, and prolonged recovery period.[5,10,17]

After cardiothoracic surgeons began to treat thoracic cavity diseases using video-assisted thoracoscopic surgery, spine surgeons adopted the technology to treat spinal disease diseases in the 1990s.[8] Over the past 2 decades, with the potential for decreased pain, blood loss, and hospital stay, neurosurgical and orthopedic spine surgeons have adopted thoracoscopy-assisted surgeries for thoracic discectomy, corpectomy, and scoliosis correction with or without instrumented fusions. While a number of centers have widely applied the thoracoscopic technique for treating thoracic spine pathologies, the technical demands and the steep learning curve associated with this technique are well recognized.[1,3,7,9,13] In their current report, Bisson and colleagues[2] present the results obtained in 25 patients who underwent thoracoscopic discectomy and instrumented fusion in which the MACS-TL plate was used. Although they conclude that thoracoscopic discectomy and plate fixation can be achieved with acceptable results and morbidity, their study demonstrated a 32% perioperative morbidity and mortality rate that is quite high. The question remains whether a learning curve may be implicated in the high complication rate, which can be reduced with experience over time. We need additional clinical studies, large patient sample size, and long-term follow-up data to address this issue, but despite having adopted this technique nearly 2 decades ago, we are still in need of those studies.

A fundamental task in comparing traditional open transthoracic and thoracoscopic thoracic discectomy is determining the underlying cause for the differences in the respective complication rates. While the 2 procedures share the same anterolateral trajectory toward the spinal canal to achieve an identical goal for discectomy and cord decompression, they differ in terms of visualization. Although advancement in endoscopic technology—improvement in fiberoptic camera and high-resolution video monitors—has significantly enhanced our ability to visualize surgical anatomy since its advent, endoscopic visualization remains 2D, which can compromise the surgeon's ability to fully appreciate the 3D anatomy required to microsurgically dissect adherent tissues on the thecal sac that can lead to durotomy or neurological injury. Additionally, the 2 procedures have different requirements in surgical instruments. Thoracoscopic spinal surgery requires longer instruments that need to be accommodated and manipulated through small apertures of the port sites at the skin. With longer instruments, the tactile feedback to the surgeon is significantly diminished. It is a concern particularly when one is using sharp tools such as curette and power drill. Moreover, minor movements of the surgeon's hands are magnified by the length of the instruments that can lead to overshooting of intended movement. The differences in our ability to manipulate surgical tools in the setting of compromised 3D visualization in thoracoscopic procedures are all likely contributing factors to the procedures' higher complication rates compared with open transthoracic procedures. As seen with endoscopic surgery in general surgery and cardiothoracic surgery, advancements in endoscopy and dedicated endoscopic instruments, along with increased surgical experience, will all be essential to improve safety and promote wide acceptance of this technique among the spine surgeons.

In the present study, Bisson and colleagues[2] demonstrate that improvements in surgical tools and spinal instrumentation over the past decade have now allowed for a minimally invasive thoracoscopic procedure in which decompression and stabilization of the spine are performed with an anterior plate and screw construct. While the perioperative complication rate remains relatively high, Bisson and colleagues found that pain was reduced during the early postoperative period and that this reduction persisted up to 2 years. Clearly, thoracoscopic spinal surgery can be effective, but it will not be the safest or the most ideal procedure for every spine surgeon or for every thoracic spinal pathological entity. We have already seen the pendulum swing away from thoracoscopic anterior instrumented fusion for scoliosis correction over the past decade, despite the initial fervor in the late 1990s and early 2000s as a result of the steep learning curve.[12] To determine the true efficacy of thoracoscopic spinal procedure compared with other approaches, we need larger clinical studies with long-term outcome follow-up data from and surgeons centers that have matured experience with this technique. The authors should be congratulated for their early results in this endeavor. I am hopeful that Bisson and colleagues will continue to build on their early experience to determine if indeed the outcomes of thoracoscopic spinal surgery can significantly improve with maturation of surgical technique and experience. *(DOI: 10.3171/2011.2.FOCUS1131)*

**Disclosure**

The author is a consultant for DePuy Spine and Medtronic.

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**Neurosurg Focus 30 (4):**E17, 2011

# Quality assessment of a new surgical simulator for neuroendoscopic training

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*Object.* Ideal surgical training models should be entirely reliable, atoxic, easy to handle, and, if possible, low cost. All available models have their advantages and disadvantages. The choice of one or another will depend on the type of surgery to be performed. The authors created an anatomical model called the S.I.M.O.N.T. (Sinus Model Oto-Rhino Neuro Trainer) Neurosurgical Endotrainer, which can provide reliable neuroendoscopic training. The aim in the present study was to assess both the quality of the model and the development of surgical skills by trainees.

*Methods.* The S.I.M.O.N.T. is built of a synthetic thermoretractable, thermosensible rubber called Neoderma, which, combined with different polymers, produces more than 30 different formulas. Quality assessment of the model was based on qualitative and quantitative data obtained from training sessions with 9 experienced and 13 inexperienced neurosurgeons. The techniques used for evaluation were face validation, retest and interrater reliability, and construct validation.

*Results.* The experts considered the S.I.M.O.N.T. capable of reproducing surgical situations as if they were real and presenting great similarity with the human brain. Surgical results of serial training showed that the model could be considered precise. Finally, development and improvement in surgical skills by the trainees were observed and considered relevant to further training. It was also observed that the probability of any single error was dramatically decreased after each training session, with a mean reduction of 41.65% (range 38.7%–45.6%).

*Conclusions.* Neuroendoscopic training has some specific requirements. A unique set of instruments is required, as is a model that can resemble real-life situations. The S.I.M.O.N.T. is a new alternative model specially designed for this purpose. Validation techniques followed by precision assessments attested to the model's feasibility.
*(DOI: 10.3171/2011.2.FOCUS10321)*

**Key Words** • **neuroendoscopy** • **surgical training** • **simulation** • **validation**

Neurosurgical skill formation is a long, consuming process. During the first years of resident training, initial support is provided by anatomical lectures and direct or indirect (video sessions) observation of surgeries. However, improvement in surgical techniques and manual skills must still be accomplished through laboratory training followed by supervised surgeries.

Several models are used in surgical training: cadaveric or animal models as well as surgical simulators.[2,4,5,7,8,10–12,14–16,22–24] Unfortunately, financial, technical, and operational obstacles more often limit their application. Thus, anatomical models built from a myriad of materials[2,14,16,24] and using computational and artistic techniques[12] have become an interesting option in simulating endoscopic procedures with good accuracy at reasonable costs.

Ideal training models should be entirely reliable, atoxic, easy to handle, and, if possible, low cost. All available models have their advantages and disadvantages. The choice of one or another will depend on the type of surgery to be performed. Cadaveric models are broadly used for microneurosurgical training. However, for neuroendoscopic training, the lack of ventriculomegaly in most cadaveric specimens limits their application.[8] Furthermore, the formol used for preservation is toxic and sometimes makes practicing uncomfortable.

Animal models are also useful in surgical training.[4] They are well accepted and applied by general surgeons. However, ethical issues as well as a poor similarity between animal and human brains make animal models unreliable. One must also consider the high costs involved in maintaining an in vivo experimental laboratory.

Finally, surgical simulators can be divided in 2 types:

virtual reality simulators and real anatomical models.[1,3] Although very promising, the use of 3D renderings and virtual reality settings are still at the development phase and are quite costly for widespread use. Furthermore, they do not allow the use of real instruments.

Hence, in conjunction with the Pro Delphus Company we created a real anatomical model called the S.I.M.O.N.T. (Sinus Model Oto-Rhino Neuro Trainer) Neurosurgical Endotrainer, which can provide reliable neuroendoscopic training. The aim of this study was to assess both the quality of the model and the development of surgical skills by trainees.

## Methods

The S.I.M.O.N.T. is built with a synthetic thermoretractable and thermosensible rubber called Neoderma (Pro Delphus Company), which, combined with different polymers, produces more than 30 different formulas, as described in detail in previous publications. These formulas present textures, consistencies, and mechanical resistance similar to many human tissues. The Endotrainer can be used for neuroendoscopic, rhinological, and endonasal skull base surgical training (Fig. 1).[14,24]

Silicon and fiberglass molds in the shape of the cerebral ventricles constitute the basic structure of the neuroendoscopic module trainer. An artist completes the setup by setting intraventricular structures, such as the choroid plexus and blood vessels, as well as pathological conditions, such as tumors and cysts. “Basic” models present only ventriculomegaly, whereas “advanced” models present several lesions that can be treated via neuroendoscopic approaches.

Regarding safety, the acrylic and resin used to build the model are odorless and nontoxic and do not deteriorate over time, and thus do not pose any biological or chemical hazards to the surgeons and technicians.

Quality assessment of the model was based on qualitative and quantitative data obtained from training sessions performed by 9 experienced and 13 inexperienced neurosurgeons. Initially, the S.I.M.O.N.T. was presented to 9 neurosurgeons with extensive experience in neuroendoscopic surgery (participation in more than 100 procedures). The technique used for preliminary evaluation was the face validation. That is, resemblance to real-life situations during practice sessions was based on expert opinions.[20]

Subsequently, the model’s precision was assessed in 2 ways: retest reliability (stability of the results between multiple assessments) and interrater reliability (similar results between multiple assessments performed by 2 different surgeons).[20] “Advanced” model simulators with multiple ventricular lesions were prepared and “operated on” several times by the experts. The end points analyzed were the time required to complete the procedure and the surgical technique applied to resect the tumors as relates to the use of instruments and ventricular navigation.

The quality of the model was further assessed using the technique called “construct validity.”[20] During this process, novices and experienced neurosurgeons performed 2 simulated surgeries (third ventriculostomy and resection of a small ventricular tumor located around the head of the caudate nucleus). To be considered valid, the model should have the ability to discriminate between the novices and the experienced surgeons.

Evaluation of the trainees’ learning curves was undertaken in a step-by-step process. After careful theoretical explanations and lab demonstrations, the trainees were invited to perform their own procedures on the simulators. Proper instrument handling, adequate ventricular navigation, and surgical technique were closely observed and objectively assessed in terms of the time required to accomplish each step (limit of 5 minutes to assemble the neuroendoscope, 5 minutes to cannulate and navigate inside the lateral ventricle, and 40 minutes to resect a small ventricular tumor). The trainees performed from 3 to 10 procedures with the assistance of an expert. All mistakes were noted and classified according to Table 1. The Poisson distribution was used for statistical analysis.

## Results

The experts considered the S.I.M.O.N.T. capable of reproducing surgical situations as if they were real and of presenting great similarity with the human brain. Furthermore, surgical results achieved from serial training were similar in both assessments (retest reliability and interrater reliability). Resection of the ventricular tumor was completed in between 40 and 50 minutes, while ventricular navigation (pivot and slide) and surgical technique remained almost identical. Thus, the model was considered precise.

Note, however, that 3 novices (23.08%) performed only partial tumor resection on their first attempt. Total resection was performed by 10 novices (76.92%) with a mean time of 78 minutes (range 67–92 minutes). Training performance was mainly characterized by incorrect/uncomfortable surgical positioning, many hesitant movements, mistaken ventricular navigation, and incorrect use of surgical instruments (Fig. 2).

Even so, the development and improvement of surgical skills was observed and considered relevant to further training. No errors were observed after the sixth procedure. Table 2 summarizes these data.

It was also observed that the probability of any single error was dramatically decreased after each training session, with a mean reduction of 41.65% (range 38.7%–45.6%). For instance, the likelihood of incorrect instrument handling was as high as 90% in the first session and dropped to 20% with further practice (Fig. 3).

## Discussion

For centuries, the apprenticeship method has been considered the gold standard for surgical training.[3,6,9,17] The paradigm of “see one, do one, teach one” clearly reveals its educational process. It is a time-honored approach in which a skillful mentor provides practical demonstrations and shares theoretical knowledge with trainees. Therefore, surgery is learned by example and repetition. But this model of training demands a very large number and variety of cases to make a new surgeon.[21]

At the end of the 1800s, William Osler and William Halsted were responsible for spreading and popularizing

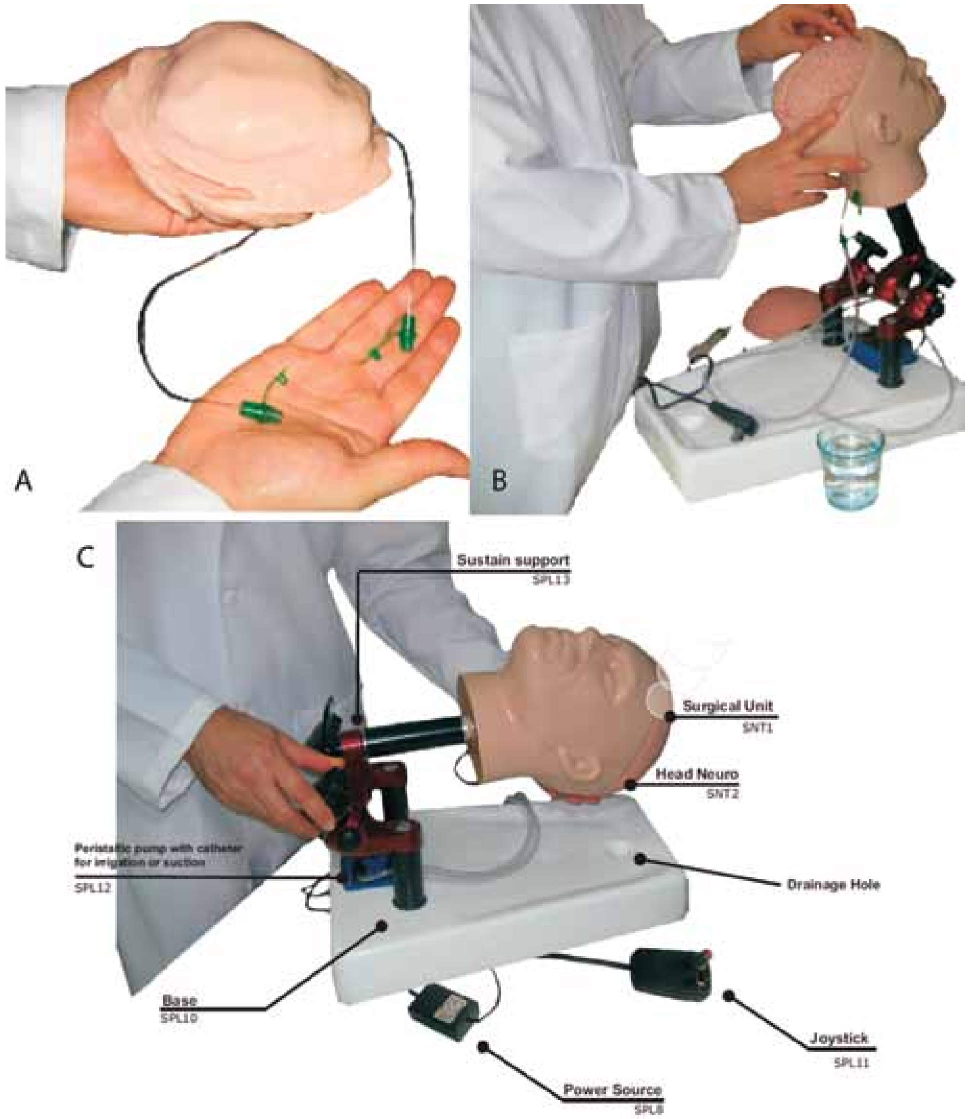


**Fig. 1.** **A:** The neuroendoscopic module trainer. **B:** Fiberglass skull and rubber layer. **C:** The S.I.M.O.N.T. ready for use.

this method.[3,6] They also established a more formal and structured system involving a team of trainees and masters.[6] In fact, the model of residency training currently applied in the majority of medical schools derives mostly from their ideas. Surgical rotations and close relationships between masters and novices guide surgical skill formation, optimizing and amplifying the learning curve. Finally, on completion of the residency program, residents must demonstrate their proficiency through examination boards to be fully certified.

Although the current apprenticeship system of training has been proven, restrictions in resident work hours, financial pressure, patient safety, and heated debates about early specialization, duration of training, and the search for a better quality of life have led some renowned surgeons to propose important alterations to this teaching method.[6,17,18] Furthermore, technological advances, such as computer-based simulators, have allowed young surgeons to gain surgical experience in a harmless environment and to quickly improve their skills.[19]

*Neurosurgical Lab Training*

Cadaveric dissection is broadly used for neurosurgical laboratory training. Nonetheless, neuroendoscopic practice presents many specific issues. Ventricular endoscopy is performed mostly through an enlarged, filled cavity, and the use of cadavers is less likely to provide this situation. To date, just a single study has demonstrated postmortem ventricular expansion after water injection.[22] Moreover, only fresh cadavers maintained this property.

Authors of another paper proposed a cadaveric model in which a triangular wedge of brain would be removed and the neuroendoscope would be inserted into the ventricular cavities.[8] However, reliability was further compromised given the lack of mechanical resistance (interface tissue/neuroendoscope) and unrealistic wider range of motion (pivot).

With increased subspecializations in the surgical field, residents are required to develop more skills in a relatively shorter period. However, the apprenticeship

**TABLE 1: Performance assessments**

| Parameter | Description |
|---|---|
| instrument handling | recognize the parts & assemble the neuroendoscope |
| | remain in a comfortable & ergonomic position |
| ventricular navigation | maintain the head camera in the upright position |
| | smooth movement for the duration of the procedure |
| surgical technique | proper knowledge of ventricular anatomy |
| | avoidance of iatrogenic injuries during entire procedure |
| | adequate use of surgical instruments |

method is tailored on a time basis. The development and use of newly created simulators in residency programs has promoted a shift in surgical education. Through harmless repetition and in an emotion-free environment, the residents can theoretically gain extensive experience in a brief duration of time.[19]

Recently, Malone et al.[12] published an interesting paper in which they discuss the current techniques of computer-based simulation in neurosurgery. These authors concluded that there are some limitations impairing the widespread use of these virtual reality models. Realistic simulation requires fidelity (high-resolution images) and strong interactivity between surgeon and machine.[1] However, tissue reactivity to manipulation and haptic feedback (tactile sensation experienced by the surgeon) remain unreliable to a certain degree.[12,18]

Nonetheless, based on the clear advantages of teaching surgery through simulation, we created the S.I.M.O.N.T., especially designed for endoscopic training.[14,24] Similarity between the model and the human brain can be attested to in the pictures (Figs. 4 and 5) and videos. After initial facial validation, the model had its reliability and method of construction strenuously assessed through several practice sessions with many different neurosurgeons. The results proved that an expert would make a very similar decision in both virtual and real-life situations.

Likewise, it was observed that less skilled surgeons seemed to quickly improve their surgical abilities. Hence, we established a simple manner to objectively evaluate the learning curve of the trainees. Through a progressive and modular approach, the major steps of any neuroendoscopic procedure, such as instrument handling, ventricular navigation, and surgical technique, were didactically taught and followed by laboratory training sessions with the Neurosurgical Endotrainer.

Fig. 2. Photographs from a training session. **A:** Incorrect use of surgical instruments. **B:** Head camera in the wrong position. **C:** Uncomfortable and nonergonomic position. Reprinted with permission from Zymberg et al.: **Minim Invas Neurosurg 53:**44–46, 2010.

After theoretical explanations and lab demonstrations performed by an expert, the novices were instructed to perform several neuroendoscopic procedures in which they could perform ventriculostomies and resect small ventricular tumors. Under careful observation and immediate feedback, all mistakes were noted. As demonstrated before, serial practical exercises showed a remarkable decrease in the number of errors. To our knowledge, this model is,

**TABLE 2: Quantitative assessment of surgical skills: number of mistakes**

| Procedure & p Value | Instrument Handling | Ventricular Navigation | Surgical Technique | Total |
|---|---|---|---|---|
| 1st | 26 | 23 | 11 | 60 |
| 2nd | 23 | 19 | 11 | 53 |
| 3rd | 17 | 11 | 6 | 34 |
| 4th | 6 | 4 | 4 | 14 |
| 5th | 4 | 2 | 1 | 7 |
| 6th | 1 | 0 | 0 | 1 |
| p value | 0.006 | 0.004 | 0.012 | 0.005 |

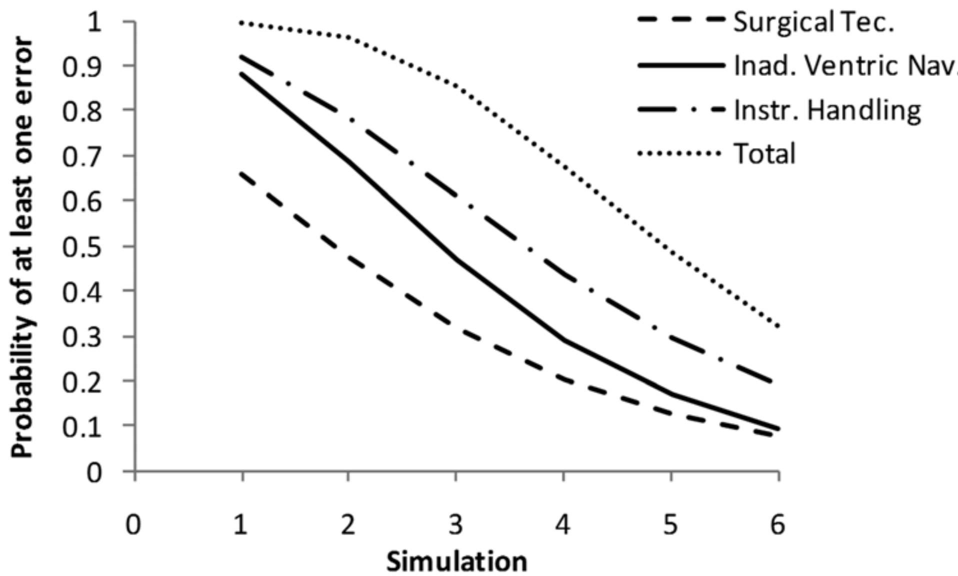


**Fig. 3.** Graph demonstrating the probability of error occurrence. Inad. = inadequate (incorrect); Instr. = instrument; Nav. = navigation; Tec. = technique; Ventric = ventricular. Reprinted with permission from Zymberg et al.: **Minim Invas Neurosurg 53:**44–46, 2010.

to date, the only one considered valid for neuroendoscopic training as well as the only one that provides formative assessment, which demonstrated efficient learning.

Its simplicity, low maintenance, flexibility, and cost-effectiveness allow practicing in small centers where financial constraints are present on a daily basis.[13] Consequently, the S.I.M.O.N.T. can also be considered a feasible tool that is worth using in any neurosurgical residency program. Neurosurgeons interested in training or organizing courses with these models can directly contact the Pro Delphus Company.

## Conclusions

Neurosurgical education is a continuous and complex process that involves several particular issues. During the last decade, innumerable factors, such as an increasing demand for subspecialists, have forced some adaptations to the current method of training. In fact, residents have been pushed to develop their surgical skills in a relatively shorter period of time.

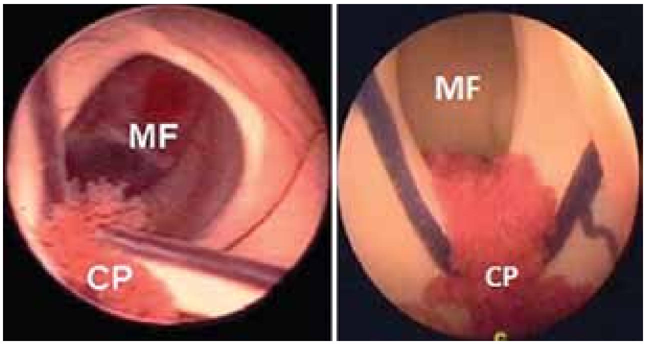


**Fig. 4.** Surgical pictures demonstrating real surgery **(A)** and simulated surgery **(B)**. CP = choroid plexus; MF = Monro foramen. Reprinted with permission from Zymberg et al.: **Minim Invas Neurosurg 53:**44–46, 2010.

Neuroendoscopic training has some specific requirements. A unique set of instruments is required, as is a model that can resemble real-life situations. Neither cadaveric nor animal models possess the properties needed for a "real," accurate ventricular endoscopic procedure. The lack of ventricular enlargement, among several other aspects, has impaired the widespread use of such models.

Such obstacles encouraged us to create and develop a new method of providing efficient neurosurgical training in the endoscopic field. The S.I.M.O.N.T. is a new alternative model specially designed for this purpose. Validation techniques followed by precision assessments attested to the model's feasibility. Thus, we believe that this simulator can be of great use for all neurosurgeons pursuing initial, advanced, or complementary training in this area.

### Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Vaz Guimarães Filho,

**Fig. 5.** Surgical pictures demonstrating simulated surgery **(A)** and real surgery **(B)**. Reprinted with permission from Zymberg et al.: **Minim Invas Neurosurg 53:**44–46, 2010.

Coelho, Zymberg. Acquisition of data: Vaz Guimarães Filho. Analysis and interpretation of data: Vaz Guimarães Filho, Coelho, Cavalheiro, Zymberg. Drafting the article: all authors. Critically revising the article: all authors. Reviewed final version of the manuscript and approved it for submission: Vaz Guimarães Filho, Cavalheiro, Lyra, Zymberg. Statistical analysis: Vaz Guimarães Filho, Coelho. Administrative/technical/material support: Lyra. Study supervision: Vaz Guimarães Filho, Zymberg.

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# Erratum

## Egas Moniz (1874–1955) and the "invention" of modern psychosurgery: a historical and ethical reanalysis under special consideration of Portuguese original sources

To The Editor: Thank you for publishing our paper, "Egas Moniz (1874–1955) and the 'invention' of modern psychosurgery: a historical and ethical reanalysis under special consideration of Portuguese original sources" (*Neurosurg Focus 30(2):*E8, 2011).

After publication we found 2 near-identical errors in our paper. The second sentence of the *Abstract* originally stated: "He performed the first prefrontal leukotomy in 1935—about 75 years ago—with the help of neurosurgeon John F. Fulton (1899–1960)," and the sixth sentence of the *Introduction* originally stated: "He performed the first prefrontal leukotomy with the help of neurosurgeon John F. Fulton (1899–1960) in 1935." These statements are incorrect. Egas Moniz was aided by Almeida Lima. The following corrections have been made:

In the *Abstract*:

> He performed the first prefrontal leukotomy in 1935—about 75 years ago—with the help of neurosurgeon Almeida Lima (1903–1985).

In the *Introduction*:

> He performed the first prefrontal leukotomy with the help of neurosurgeon Almeida Lima (1903–1985) in 1935.

We apologize for this inexplicable mistake, and we appreciate the opportunity to correct the errors. The corrections were made online as of April 1, 2011. *(DOI: 10.3171/2011.3.FOCUS10214a)*

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