Supracerebellar infratentorial endoscopically controlled resection of pineal lesions: case series and operative technique

Clinical article

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Object. The heterogeneous clinical manifestations and operative characteristics of pathological entities in the pineal region represent a significant challenge in terms of patient selection and surgical approach. Traditional surgical options have included endoscopic transventricular resection; open supratentorial microsurgical approaches through the midline, choroidal fissure, lateral ventricle, and tentorium; and supracerebellar infratentorial (SCIT) approaches through the posterior fossa. The object of the current study was to review the preoperative characteristics and outcomes for a cohort of patients treated purely via the novel endoscopically controlled SCIT approach.

Methods. A single-institution series of 9 consecutive patients (4 male and 5 female patients [10 total cases]; mean age 21 years, range 6–37 years) treated via the endoscopically controlled SCIT approach for a pathological entity in the pineal region was retrospectively reviewed. The mean follow-up time was 13.2 months.

Results. The endoscopically controlled SCIT approach was successfully used to approach a variety of pineal lesions, including pineal cysts (6 patients), epidermoid tumor, WHO Grade II astrocytoma (initial biopsy and recurrence), and malignant mixed germ cell tumor (1 patient each). Gross-total resection and/or adequate cyst fenestration was achieved in 8 cases. Biopsy with conservative debulking was performed for the single case of low-grade astrocytoma and again at the time of recurrence.

The mean preoperative tumor and cyst volumes were 9.9 ± 4.4 and 3.7 ± 3.2 cm³, respectively. The mean operating times were 212 ± 71 minutes for tumor cases and 177 ± 72 minutes for cysts. Estimated blood loss was less than 150 ml for all cases. A single case (pineal cyst) was converted to an open microsurgical approach to enhance visualization. There were no operative complications, as well as no documented CSF leaks, additional CSF diversion procedures, or air emboli. Seven patients underwent concomitant third ventriculostomy into the quadrigeminal cistern. At the time of the last follow-up evaluation, all patients had a stable or improved modified Rankin Scale score.

Conclusions. The endoscopically controlled SCIT approach may be used for the biopsy and resection of appropriately selected solid tumors of the pineal region, in addition to the fenestration and/or resection of pineal cysts. Preoperative considerations include patient presentation, anticipated disease and vascularity, degree of local venous anatomical distortion, and selection of optimal paramedian trajectory. (DOI: 10.3171/2011.8.PEDS1157)

Key Words • supracerebellar infratentorial approach • pineal region • endoscopy • three-dimensional endoscopy
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Our institution previously reported a case in which a pineal cyst was resected via a completely endoscopic (that is, endoscopically controlled) SCIT approach through a burrhole craniotomy. Since that time, we have successfully applied this minimally invasive technique for the resection of a host of pineal lesions, including an epidermoid tumor, a low-grade pineal glioma, pineal cysts, and a pineal germinoma. As previously reported, the approach, which is performed with the patient in the seated position, allows for minimal brain retraction, avoidance of fornical transection or traction, avoidance of cortical transgression, favorable visualization irrespective of ventricular volume, ideal illumination through an air medium, enhanced working corridors with the use of an angled endoscope, and early visualization and control of the galenic complex. It is also possible to perform a concomitant ETV by creating a fenestration between the third ventricle and the quadrigeminal cistern. In this paper we discuss our experience and the technical aspects of the endoscopically controlled SCIT approach. Strategies for patient selection, anticipated innovations in the field of neuroendoscopy, and a review of 9 lesions of the pineal region resected via this approach are also presented.

Methods

This study was approved by the Institutional Review Board at St Joseph’s Hospital and Medical Center.

The medical records of all patients treated for pathological entities in the pineal region via the endoscopically controlled SCIT approach at the Barrow Neurological Institute were retrospectively reviewed. Procedures converted from primarily endoscopic to open microsurgical approaches were included. Patients undergoing a primarily open approach with postresection endoscopic assistance, however, were excluded from consideration. Nine patients (4 male and 5 female patients [10 total cases]; mean age 21 years, range 6–37 years) were identified. These patients underwent 10 endoscopically controlled SCIT procedures.

Preoperative and Postoperative Evaluation

At the time of the initial consultation, all patients underwent a detailed neurological examination. This preoperative assessment included the following: motor scores; sensory examination; reflexes; and documentation of associated symptoms such as headaches, visual complaints, and functional status as measured by the mRS in all cases. Their medical and/or surgical history, including prior surgical interventions, CSF diversion procedures, conservative therapies, and smoking history were also noted from the medical records. Preoperative MR imaging (all patients) and in some instances CT imaging studies were evaluated for the presence of hydrocephalus, ventriculomegaly, aqueductal compression, and the measurement of mass size. Imaging results were tabulated based on the preoperative assessment of the radiologist and operating surgeon to avoid post hoc bias.

All patients underwent detailed neurological assessment postoperatively in the outpatient neurosurgical clinic. The mean clinical follow-up was 13.2 months, and radiographic follow-up was 3.4 months. Primary outcome measures included neurological assessment at last follow-up, presence or absence of headaches or other presenting symptoms (for example, nausea and/or vomiting), new postoperative deficits, functional status (mRS score), evidence of hydrocephalus at last follow-up, death, and need for repeat operation. Secondary outcome measures included need for postoperative CSF diversion (for example, ventriculoperitoneal shunt, ETV), CSF leak, adjuvant therapies, presence of Parinaud syndrome, operating time, estimated blood loss, and any evidence of lesion recurrence on imaging studies, based on the surgeon’s and/or neuroradiologist’s interpretation. Craniotomy size was calculated from the operative record and/or available postoperative imaging.

Surgical Technique

Patients underwent preoperative assessment in which echocardiography was performed with a bubble study to rule out the presence of a patent foramen ovale or other right-to-left cardiac shunts. In the operating room, patients were padded and placed in the seated position with gentle capital flexion and secured to the rigid Mayfield frame. This slight flexion helped to level the angle of the tentorium (in comparison with the standard seated position) and provides a more favorable working trajectory through the posterior fossa. Postpositioning somatosensory evoked potentials were compared with prepositioning baseline levels before proceeding further. Additional monitors including precordial Doppler ultrasonography (to evaluate for air embolus) and central line placement were also routinely used for all patients who were treated while in the seated position. The patient’s preoperative volumetric MR imaging study, which was obtained after the addition of contrast material, was loaded into the Treon Plus Stealth Station (Medtronic Navigation), and surface registration was performed. A SureTrak universal instrument adaptor (Medtronic Navigation) fixed to the endoscope and trocar allowed for scope-based frameless stereotactic navigation throughout the procedure.

An approximately 3-cm vertical incision was followed by a 1.5- to 2.5-cm burr hole or microcraniectomy placed at the inferior margin of the transverse sinus. As our experience grew, we preferred to bias the craniotomy 1–2 cm lateral to the torcula. The dural leaflets were opened in a cruciate or semilunar fashion. The endoscope was used for preliminary evaluation of cerebellar relaxation. Mannitol or CSF drainage (via a preoperatively placed lumbar drainage catheter in all but one case; an external ventricular drain was used in that case) were used in selected cases to enhance gravity-based retraction. No fixed retractors were used during any of the cases.

The endoscope was advanced along the lower margin of the tentorium. Arachnoidal adhesions were sharply cut. Minor tentorial bridging veins along a wide corridor were coagulated and cut on the bias toward the cerebellar surface to avoid later avulsion during removal, angulation, or replacement of the endoscope. On arrival at the deep venous (galenic) confluence, the endoscope was directed at the level of the pathological entity, and the coronally oriented arachnoid adhesions were opened sharply with
microscissors. In a single case of pineal cyst resection, dissection of the cyst proceeded as previously described, using a “bimanual” technique through the principal and side ports of the endoscope. During this process, I operator directed the “bimanual” technique, while the assistant stabilized or directed the endoscope.

In the remainder of the cases, the instruments were used independently of the endoscope; that is, we did not routinely pass instruments through the endoscope ports. Standard microsurgical instruments, including micro dissectors, pituitary forceps, and ultrasonic aspirators were used under endoscopic visualization. Sharp dissection with gentle traction from grasping forceps was preferred over blunt dissection whenever possible.29 The cerebellar surface was protected with Telfa cottonoids when instruments were brought into the field outside of the scope portals. We used 0°, 30°, and 45° angled endoscopes to aid in visualization and to enable additional piecemeal resection. In the most recent cases, we converted to the use of 3D endoscopic technology (6.5-mm outside diameter, 0° and 45° endoscopes, Visionsense Ltd.). Bleeding was easily controlled with bipolar cautery, light manual tamponade over Gelfoam, or hemostatic agents such as Surgifoam. Adequate specimens were sent for pathologi cal examination.

At the completion of the resection, the dura mater was closed primarily to the extent possible. Dural closure was reinforced with dural substitute graft onlay (for example, Duragen, Integra Life Sciences Co.), followed by sealant (for example, DuraSeal, Covidiem Healthcare). The wound was closed in multiple layers. Conservative lumbar or external ventricular drainage (when applicable) was discontinued between 0 and 36 hours postoperative- ly. All patients underwent repeat imaging in the immediate postoperative period.

Results

Patient Characteristics

Preoperative symptoms, imaging characteristics, and observation periods are documented in Table 1. One patient treated for a low-grade tectal glioma had previously undergone ETV at another institution via a standard pre coronal bur hole. A pineal biopsy was not performed at the time of the initial ETV. He had been followed for 119 months, with stable disease based on results of scans and on his symptoms. An endoscopically controlled SCIT biopsy procedure was elected due to rapid tumor growth and symptomatic deterioration from his prior baseline. Ventricular size was unchanged. The goal of surgery was biopsy and debulking. Additional debulking via the same endoscopically controlled SCIT approach was performed 8 months later secondary to disease and symptomatic progression with increasing enhancement. Radiographic findings before surgery are also found in Table 1. Enhancing septations and atypical signal characteristics (for example, thick walls) complicated the preoperative radiological differential diagnosis in 2 cases of pineal cysts.

Operative parameters and complications are listed in Table 2. A single case of pineal cyst removal was convert ed to open microsurgical resection due to inadequate visualization. Despite the patient’s seated position, cerebeller relaxation was insufficient to gain the necessary inferiorly directed view to the pineal region. A lumbar drain was not available in this patient. The resection proceeded uneventfully with the aid of microscopic guidance, but the patient required a superficial wound revision within 30 days. Wound breakdown was attributed to excessive cautery during extension of the skin incision. The size of the craniotomy was not enlarged. There was no CSF leak at the time of repeat operation.

Symptom resolution and outcomes are also listed in Table 2. One patient with a pineal cyst reported no change in preoperative symptoms, despite a reported improvement in functional independence and cognitive performance. This patient’s initial presentation was complicated by a history of developmental disability and cognitive decline. The single case of preoperative Parinaud syndrome resolved after gross-total resection of an epidermoid tumor. A single case of new permanent neurological deficit at last follow-up, subjective left-sided tingling and sensory changes, was reported following removal of a mixed germ cell tumor. The mRS score was stable or improved in all patients at last follow-up.

Illustrative Cases

Case 1

History and Examination. This 12-year-old boy presented to his pediatrician with complaints of 1 month of headache and nausea and was found to have evidence of bilateral papilledema. His headaches were nonpositional. He had no other remarkable medical or headache history. He was transferred to the emergency room for urgent imaging, and was found to be neurologically intact, including grossly normal visual acuity, cranial nerve function including extraocular movements, sensation, and strength. There was no evidence of nystagmus or Parinaud syndrome.

Neuroimaging. Admission CT imaging revealed a pineal region hyperdensity with scattered calcification, particularly at the third ventricular face of the lesion. Marked triventricular hydrocephalus, transependymal edema, and mild sulcal effacement were noted. Preoperative MR imaging (Fig. 1A) revealed a 2.1 × 1.4–cm heterogeneously enhancing, lobular pineal region mass with low T2 signal. Serum β-human chorionic gonadotropin and α-fetoprotein were normal preoperatively. The diagnosis of germinoma was favored based on the patient’s age, imaging findings, and presentation. Choriocarcinoma, embryonal cell carcinoma, and endodermal sinus carcinoma were considered unlikely due to lack of dissemination or systemic involvement. The CSF markers were not obtained. Pineoblastoma and pineocytoma were also considered to be less likely.

Biopsy. The patient underwent right transfrontal transforaminial ETV and biopsy of the pineal region mass on the following day. This approach was selected for the biopsy procedure, due to our anticipation that the
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### TABLE 1: Presenting symptoms and demographic and imaging characteristics in 9 patients with pineal region lesions

<table>
<thead>
<tr>
<th>Factor</th>
<th>Solid Tumors (4 cases)</th>
<th>Cysts (6 cases)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>demographic data</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean age</td>
<td>24.0 yrs</td>
<td>26.1 yrs</td>
</tr>
<tr>
<td>sex (M/F)</td>
<td>4:0</td>
<td>1:5</td>
</tr>
<tr>
<td><strong>pathological entity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 epidermoid, 1 malignant mixed germ cell, 1 Grade II glioma</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td><strong>symptoms</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>headache</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>nausea /&amp;or emesis</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Parinaud syndrome</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>visual (excluding Parinaud syndrome)</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>cognitive impairment</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>dysequilibrium</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>papilledema</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>preop evaluation w/ neurology specialist</strong></td>
<td>NA</td>
<td>6</td>
</tr>
<tr>
<td>mean observation time</td>
<td>NA</td>
<td>3.5 ± 2.1 mos</td>
</tr>
<tr>
<td><strong>imaging findings</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean tumor or cyst size</td>
<td>9.9 ± 4.4 cm³</td>
<td>3.7 ± 3.2 cm³</td>
</tr>
<tr>
<td>hydrocephalus</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>aqueductal compression</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

* The means are expressed ± SD throughout. Abbreviation: NA = not applicable.
† Three patients underwent 4 endoscopically controlled SCIT procedures for the resection of solid tumors. One patient with a low-grade glioma underwent repeat resection after symptomatic and radiological progression. The goal of surgery in each case was biopsy and debulking rather than gross-total resection. Preoperative findings from each operative setting are included.

lesion represented a highly radiosensitive tumor. The initial ETV was performed without complication, and the angle of the 30° endoscope was reversed to visualize the posterior aspect of the third ventricle. A heterogeneous mass more closely resembling a teratoma was readily apparent. Multiple, discrete components, which appeared calcified and gliotic in nature, were identified. Multiple samples were taken for biopsy with grasping forceps. The ventricles were irrigated until clear; a ventriculostomy catheter was left in the lateral ventricle, and the wound was closed in the standard fashion. Pathological examination revealed a heterogeneous mass with numerous small cysts, lymphoid aggregates, and fragments of squamous epithelium with paucicellular keratinaceous debris. Mitotic figures and carcinomatous features were absent, favoring the diagnosis of mature teratoma.

**Definitive Resection.** The patient was allowed to recover for 5 days before definitive resection via the endoscopic SCIT approach. Endoscopic resection was deemed feasible due to the favorable planes, along with the discrete, avascular nature of the mass observed during the biopsy. The infratentorial craniotomy was centered approximately 1.5 cm to the right of the torcula, and proceeded as described above, with the aid of a 3D endoscope (Video 1).

**Video 1.** Edited clip showing surgery in Case 1. Used with permission from Barrow Neurological Institute. Click here to view with Windows Media Player. Click here to view with Quicktime.

The arachnoid was opened over the right lateral venous confluence, and a suitable corridor for resection was identified lateral to the superior cerebellar venous complex and inferior to the basal vein of Rosenthal. A combination of ultrasonic aspiration, sharp dissection with gentle traction, and microdissection was used to remove the calcified portion of the tumor. The mass easily dissected from the cerebellum posteriorly, from the thalamus anteriorly, and from the galenic venous confluence. The internal cerebral vein could be fully visualized following removal of this component. A white, softer component inferior and lateral to the calcified portion was removed in a piecemeal fashion with microdissectors and scissors (Fig. 1C). The mass was densely adherent anteriorly along the left posterior pulvinar. The cavity and normal anatomy, including the collicular plate, venous confluence, thalamus, and posterior third ventricle were inspected with the 30° endoscope. No residual tumor was identified; all veins and normal tissue were otherwise grossly preserved, and the wound was closed.

**Pathological Features.** Pathological investigation revealed the presence of epithelial elements including squamous and glandular phenotypes, mesenchymal elements including bone, and prominent lymphoid tissue. However, the majority of the specimen contained sheets of large neoplastic-appearing cells with atypical nuclei, abundant cytoplasm, and mitotic figures. The diagnosis of malignant mixed germ cell tumor was favored on final characterization.
Postoperative Course. Postoperatively, the patient was weaned from his ventriculostomy and discharged to home on postoperative Day 8. An initial Parinaud syndrome resolved, and he reported only subjective left-sided sensory changes at last follow-up (5 months). This finding was attributed to dissection along the adherent thalamic margin of the tumor. He remained otherwise neurologically intact and functionally independent. A follow-up MR imaging study (Fig. 1B) obtained at that time was negative for residual mass, enhancement, or hydrocephalus. No further adjuvant therapies are planned.

Case 2

History and Examination. This 23-year-old man presented after referral from his primary care provider with a history of intractable lifelong nausea, progressive inter-
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mittent headaches, dizziness, and worsening intermittent upgaze palsy. His medical and surgical history was non-contributory. He displayed marked nystagmus with lateral gaze bilaterally, but was otherwise neurologically intact at the time of examination.

Neuroimaging. Admission MR images revealed a rounded lesion within the pineal gland, measuring $2.0 \times 2.2 \times 1.4$ cm at its greatest dimensions (Fig. 2A). The T1 and T2 signal characteristics followed those of CSF without significant enhancement. The lesion appeared brightly restricted on diffusion-weighted imaging. Radiological interpretation favored the diagnosis of epidermoid cyst. Triventricular hydrocephalus was apparent, with marked mass effect on the posterior third ventricle, tectum, and aqueduct.

Operation. The patient underwent resection via the endoscopically controlled SCIT approach, performed through a $2.0 \times 2.8$–cm right paramedian craniectomy. Following mannitol and lumbar drainage to enhance cerebellar relaxation, the arachnoid at the cisternal face was opened sharply (Video 2).

VIDEO 2. Edited clip showing surgery in Case 2. Used with permission from Barrow Neurological Institute. Click here to view with Windows Media Player. Click here to view with Quicktime.

Typical pearly white-to-yellow epidermoid tissue was immediately visualized eccentric to the midline venous galenic complex (Fig. 2C). The cyst contents were removed in piecemeal fashion by using a combination of suction aspiration, sharp dissection, and microdissection. A working corridor was again noted between a tributary of the superior cerebellar vein complex medially and the basal vein superolaterally. Additional fragments of diseased tissue were identified at the inferior margins only with use of a 45° angled endoscope. After confirming the resection planes and anatomy with the neuronavigation system, we

![Fig. 2. Case 2. A: Preoperative diffusion-weighted axial MR image depicting restriction indicative of a pineal region epidermoid. Increased width of the third ventricle is apparent. B: Postoperative diffusion-weighted axial MR image depicting resolution of the previously noted restriction and gross-total resection. C: Intraoperative photograph depicting piecemeal microdissection of the pearly white epidermoid contents, again working between a branch of the superior cerebellar venous complex and basal vein. The tentorium is also noted. D: Intraoperative photograph depicting the region of the pineal (P) following resection of the epidermoid cyst contents. An ETV was also completed through the thinned pineal recess by using bipolar forceps. E: Intraoperative view of the third ventricle following advancement of the endoscope through the fenestration in the pineal recess. Paired internal cerebral veins (ICV) behind the velum interpositum and choroid plexus (CP) are visualized along the roof of the third ventricle. The thalamus (Th) is noted laterally. The CSF is clear. Figures 2C–E used with permission from Barrow Neurological Institute.](image-url)
identified the pineal recess inferior to the gland. The recess was markedly thinned, avascular, and stretched, creating sufficient working room between the pineal and superior colliculus. The scissors and bipolar forceps were used to open the posterior wall of the third ventricle, and the endoscope was advanced through the stoma (Fig. 2D and E). The third ventricle walls and the internal cerebral veins were inspected, and clear CSF flow was noted through the fenestration. The wound was closed as previously described. Pathological specimens revealed lamellar keratin debris consistent with epidermoid cyst.

Postoperative Course. Postoperatively, the patient awoke without neurological deficit and was discharged on postoperative Day 2. At 5-month follow-up, his quality of life had improved, and his headaches and nausea had resolved. The MR imaging study (Fig. 2B) obtained at that time was negative for recurrence, areas of restricted diffusion, or evidence of hydrocephalus. A follow-up MR imaging study is planned for 1 year.

Discussion

Prior to this publication, a single technical description of a fully endoscopic SCIT approach for the resection of a single pineal cyst was previously reported by the senior author (P.N.)29 Arachnoid48 and ependymal cysts45 have also been fenestrated through a similar posterior fossa route, with purely endoscopic instrumentation and with endoscopic assistance. Many of the indications, advantages, and limitations of the approach were nicely reviewed in the initial case report from this institution.29 The technical feasibility and advantages of endoscopic approaches to the region of the posterior incisura, both with and without stereotactic navigation, have also been validated in cadaveric studies.11,64 The results presented here highlight the first series on clinical application of this novel approach, review the technical nuances we have learned from experience with the endoscopically controlled SCIT approach, and support its application to include carefully selected solid tumors and symptomatic pineal cysts. The essentials of the approach include the use of the sitting position and a lumbar drain to provide a working space between the cerebellum and tentorium, an off-midline approach to avoid obstruction by the vermis, and the use of microdissection technique aided by endoscopic visualization.

Pineal cysts have been reported to be fairly ubiquitous among the asymptomatic population according to imaging studies,2,45 and are believed to follow a benign natural history.4 Their relationship to headache remains controversial, and for these reasons conservative management strategies are favored for pineal cysts in the vast majority of cases.4,23 Nonetheless, operative indications for pineal glial cysts do arise and were also reviewed nicely by Gore et al.:29 in brief, these include symptomatic hydrocephalus due to aqueductal compression, visual disturbance such as Parinaud syndrome, and motor and/or sensory dysfunction due to local compression.22,29,56,62 In the absence of compelling clinical and radiological correlates, headaches may be surmised to arise from intermittent aqueductal obstruction, progressive aqueductal gliosis, or deep venous outflow obstruction.29,41,62 Careful patient selection and our hesitation to pursue aggressive surgical management in such cases is reflected by the following: the extended observation time for patients in this group (3.5 months after initial neurosurgical consultation), the uniform referral for neurological examination during that time period, the demonstrated failure of medical management in all cases, and the uniformly favorable postsurgical outcomes. Furthermore, we note that this surgical case series does not report those many more numerous patients who were unsuitable for surgical intervention or in whom we did not think that surgery was warranted.

Pineal tumors represent more than 15 distinct pathological entities20,43 and may be broadly conceptualized by cell of origin (germ cell tumors, pineal parenchymal tumors, glial cell–derived tumors, and the remainder), on a general spectrum from benign to malignant, and additionally by radiosensitivity.7,53 Surgical strategy, in terms of approach and anticipated extent of resection, is typically dependent on preoperative imaging and intraoperative pathological findings.52,43 We believe that the endoscopically controlled SCIT approach has particular advantages over the transventricular-transforaminal approach in this paradigm for the following reasons.

1) Rates of nondiagnostic or inaccurate diagnosis during transventricular endoscopic biopsy have been reported to range from 52% to 70%.1,19,24,39,40 This point is illustrated by the first case highlighted above. The diagnosis and pathological findings were appropriately modified after more extensive tissue sampling during the second procedure. This may be due, at least in part, to limited access to the lesion in the setting of small- or normal-sized ventricles. In our estimation, the endoscopically controlled SCIT approach is likely to minimize the risks of sampling bias. This corridor affords comparably wide visualization, as well as direct access to the quadrigeminal cistern where most of the lesions are typically found. For patients such as those reported in Case 1, our current paradigm has evolved to favor initial surgery via the endoscopically controlled SCIT approach over attempts at transventricular or stereotactic biopsy. 2) Gaab and Schroeder27 recommended against attempts at gross-total resection via the transventricular approach for lesions larger than 2 cm in diameter. We demonstrated resection of lesions beyond this diameter in the current series, adding support to our belief that cytoreduction and gross-total resection is more easily accomplished from the posterior approach in general. This may be credited largely to the use of more familiar and facile microsurgical instruments working in an air medium, rather than CSF. 3) The endoscopically controlled SCIT approach is readily converted to an open microsurgical dissection in the event of unfavorable planes, bleeding, cerebellar fullness, or anatomical distortion. This was illustrated by one of the cases in the current series and is clearly the exception. 4) Forniceal traction and injury is completely avoided during the endoscopically controlled SCIT approach. 5) Ventricular size and/or configuration of the massa intermedia has no impact on the utility of the endoscopically controlled SCIT approach, in comparison
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with the transventricular-transforaminal avenue.43 6) Although hemorrhagic complications during transcortical endoscopic approaches are reported to be low (3.5% or less),34 parenchymal transgression is entirely avoided by the endoscopically controlled SCIT approach.

The endoscopically controlled SCIT approach allows for management of hydrocephalus. In the setting of aqueductal compression and/or hydrocephalus due to other causes, an endoscopic fenestration from the quadrigeminal cistern into the third ventricle may also eliminate the need for additional CSF diversion (for example, ventriculo-peritoneal shunting or anteriorly placed ventriculostomy through the floor of the third ventricle). For pineal cysts, we have effectively created a "posterior ETV" by opening the avascular anterior wall of the cyst directly into the posterior aspect of the third ventricle. Anterior-to-posterior directed fenestrations (for example, via the transventricular-transforaminal approach), although reported,30,31 are anatomically less favorable. Pineal veins and the midline tributaries of the superior cerebellar vein may be draped or situated immediately behind the posterior aspect of the mass and thus cannot be visualized before transgression of the cyst wall from the anterior-posterior trajectory.29 Posterior ETV is also especially beneficial in the case of incompletely resected or fenestrated cysts. Given the relatively high likelihood of cyst recurrence in this scenario,41,57 a patent ETV may alleviate symptomatic progression, despite radiographic recurrence.31

For the mixed-type germ cell tumor presented above, gross-total removal of the tumor mass resulted in wide fenestration of the third ventricle into the cistern. For cases in which tumor resection alone is insufficient to allow communication between these compartments, alternative sites of ventriculostomy have been described. Konovalov and Pitskhelauri37 described a microsurgical safe-entry zone into the third ventricle for the removal of colloid cysts through the suprapineal recess and above the habenular commissure. An alternative endoscopic entry zone has also been described in a cadaveric study as 3 mm lateral to the pineal, parallel to the plane of the superior colliculus, and further inferior to the internal cerebral vein.21 For the epidermoid in the current series, we chose a novel entry point through a widened and thinned subpial recess. The approach in this case avoided the laterally oriented commissural fibers, pineal gland, and internal cerebral veins without undue risk to the collicular plate. Ultimately, stereotactic navigation and anatomical inspection of the tumor bed dictate the site of fenestration from among the options reviewed above. The endoscope is particularly well suited for this task compared with the microscope. The endoscope may be inserted through even a narrow stoma to inspect entry into the third ventricle for 360° with no need for a more extensive dissection. We recognize the limitations, however, of posterior ETV in the setting of extensive tumor, anatomical distortion, or inadequate visualization due to veins.

We anticipate that certain pathological entities such as epidermoid cysts, glioblastomas, selected teratomatous lesions, low-grade glial tumors, germ cell tumors, and pineocytomas may be amenable to endoscopic gross-total resection or safe biopsy. This is due to their relative avascularity, ease of aspiration or cyst collapse, and typically lobular configuration. An open microsurgical approach is advocated in the setting of highly vascular lesions, infiltrating lesions such as pineoblastoma, lesions with significant extent across the midline bilaterally, or lesions extending above the tentorium. Applications to intrinsic brainstem lesions such as cavernous malformations are likely to generate more controversy, but could be considered depending on the lesion's proximity to the pial surface, location relative important neural tissues, and size.

Control of the deep venous system remains a principal challenge in approaching midline lesions via the SCIT corridor. Sacrifice of one or more deep veins at the posterior incisura has been reported, with varied but occasionally severe clinical consequences.13,17,90 This risk is primarily mitigated by use of the seated position. Retraction of the cerebellar hemispheres and vermis away from the tentorium by gravity facilitates sharp dissection of the arachnoid planes over the veins without the need for significant additional traction.29 Additionally, this gravity retraction allows for dissection of looped vascular structures that on first inspection appear to enter the tentorium, but may in fact be dissected free without sacrifice. Second, the seated position allows for decreased venous engorgement when the neck is positioned appropriately.

We have also shifted our preferred trajectory from a midline location as reintroduced by Stein,52 in favor of a paramedian approach as described by Yaşargil.63 The important benefits of this subtle modification are amplified under minimally invasive endoscopic conditions and include the following advantages. First, complete avoidance of the torcula and occipital sinus during dural opening; and second, a less confrontational view of the galenic venous complex. In particular, the superior cerebellar vein, along with its superior vermian and precentral cerebellar tributaries,15 is visualized anteromedially to the pineal in this trajectory. In the majority of cases we found ample working space to accommodate the endoscope and several instruments between the superior cerebellar venous complex and the basal vein superolaterally during tumor and cyst resection. A similar corridor, bounded inferiorly by the quadrangular lobule of the cerebellum, was also described by Sanai et al.49 who were using a seated but open SCIT approach to the pulvinar. The internal cerebral veins, from their origin at the vein of Galen through their insertion into the velum interposum, could be progressively visualized, dissected, and preserved as resections proceeded to the deep and superior boundaries. No fixed retractors were used, and no deep veins were sacrificed in the series. Third, hemispheric bridging veins encountered during the paramedian approach drain laterally and away from the superior cerebellar venous complex. Ueyama et al.59 reported that lateral as opposed to medial hemispheric bridging veins may be more safely taken due to collateralization patterns. Although not reported in the current series, similar principles probably apply to potential endoscopic applications of an extreme lateral SCIT approach to the ambient cistern or the midline incisural space.29

The so-called bimanual technique, in which 2 instruments are inserted through the working channels of the
endoscope, was previously reported in the initial case report from this institution. Using that technique, a flexible or rigid grasping forceps applies gentle traction to the tissue. The second instrument, most commonly a rotating microscissors, is used for sharp dissection. This may be safely accomplished with the blades closed or used in the typical cutting fashion. Our ability to perform an efficient and safe resection, rather than simply to fenestrate more adherent or larger cysts, was greatly enhanced, however, by so-called endoscopically controlled microdissection. This technique, in which microdissectors are passed outside of the instrument ports and used in the standard fashion, has been well described for a variety of other intraventricular, vascular, sellar region, posterior fossa, and reconstructive applications. Endoscopically controlled resection was essential for the solid tumors and for 5 of the 6 pineal cysts reported here. Standard microsurgical tenets are maintained under endoscopic control, allowing the operator to dissect pathological tissues from nearby structures rather than to remove them by grasping or cutting under additional external traction. Minimal additional bone removal beyond a typical small bur hole, but significant attention to bridging veins during the initial dissection is required to accommodate the additional instrumentation. Our standard technique now in this approach is to emulate microsurgical technique in all respects while using endoscopic control.

The technical feasibility, learning curve, and range of indications for neuroendoscopic surgical procedures are likely to be influenced further by technological innovation. Frameless endoscope-based navigation has demonstrated considerable value for intraventricular applications and was invaluable in the current series to confirm surgical planes and boundaries. We report the use of a stereoscopic 3D endoscope in 4 cases and in each case of solid tumor resection in the current series. Learning curves, dexterity, feasibility, and subjective measures of surgeon preference have demonstrated the value of this technology both in neurosurgery and in laparoscopy. For transventricular pineal biopsy procedures, flexible endoscopy has been associated with higher rates of nondiagnostic findings. We suspect that limited visual resolution, poor depth perception, and the limited instrumentation available for use with flexible endoscopes may account for some component of these findings. The majority of such limitations are overcome with newer rigid 3D endoscopic technology. In virtual endoscopy, preoperative imaging is rendered to develop virtual surgical models at levels of detail sufficient to include local vasculature. Despite its demonstrated feasibility and utility, this technology thus far has only begun to gain clinical application. We note that such 3D image rendering may be invaluable in case selection and surgical planning for this approach. Furthermore, improved endoscopic instrumentation and continued miniaturization are likely to support additional advances.

Conclusions

The current series supports the contention that the endoscopically controlled SCIT approach is a safe, feasible, and effective alternative for the fenestration and/or resection of symptomatic pineal cysts, as well as appropriately selected solid tumors of the pineal region.

Disclosure

Dr. Bristol owns stock in Advanced Medical Devices, and she is a consultant for ev3, Inc. Dr. Nakaji serves as a consultant for Aesculap USA. Drs. Uschold, Abla, and Fusco report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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