

## Case Report

# Endoscopic approaches to brainstem cavernous malformations: Case series and review of the literature

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## Abstract

**Background:** Symptomatic cavernous malformations involving the brainstem are frequently difficult to access via traditional methods. Conventional skull-base approaches require significant brain retraction or bone removal to provide an adequate operative corridor. While there has been a trend toward limited employment of the most invasive surgical approaches, recent advances in endoscopic technology may complement existing methods to access these difficult to reach areas.

**Case Descriptions:** Four consecutive patients were treated for symptomatic, hemorrhagic brainstem cavernous malformations via fully endoscopic approaches (endonasal, transclival; retrosigmoid; lateral supracerebellar, infratentorial; endonasal, transclival). Together, these lesions encompassed all three segments of the brainstem. Three of the patients had complete resection of the cavernous malformation, while one patient had stable residual at long-term follow up. Associated developmental venous anomalies were preserved in the two patients where one was identified preoperatively. Three of the four patients maintained stable or improved neurological examinations following surgery, while one patient experienced ipsilateral palsies of cranial nerves VII and VIII. The first transclival approach resulted in a symptomatic cerebrospinal fluid leak requiring re-operation, but the second did not. Although there are challenges associated with endoscopic approaches, relative to our prior microsurgical experience with similar cases, visualization and illumination of the surgical corridors were superior without significant limitations on operative mobility.

**Conclusion:** The endoscope is a promising adjunct to the neurosurgeon's ability to approach difficult to access brainstem cavernous malformations. It allows the surgeon to achieve well-illuminated, panoramic views, and by combining approaches, can provide minimally invasive access to most regions of the brainstem.

**Key Words:** Brainstem, cavernoma, cavernous malformation, endoscopic, minimally invasive

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## INTRODUCTION

Cavernous malformations (CMs) are angiographically occult vascular lesions lined with a single layer of endothelium that displace adjacent brain tissue. The prevalence of CMs is estimated to be 0.4–0.5% in the general population and present clinically with a variety of signs and symptoms including hemorrhage, headache, seizure, or focal neurologic deficit.<sup>[13,37,43]</sup> Among all intracranial CMs, less than one-fifth are located within the brainstem, most of which are found within the pons due to its relatively large size.<sup>[21]</sup>

Brainstem CMs are of particular concern given the eloquence of adjacent neural tissue and the high likelihood of symptomatic hemorrhage. Although most supratentorial CMs are discovered incidentally, a series by Porter *et al.* of 100 patients with brainstem CMs demonstrated that 97% of patients had focal neurological deficits at diagnosis.<sup>[38]</sup> Moreover, brainstem CMs tend to have higher hemorrhage rates than other intracranial CMs, ranging from 2.3% to 8.7% for brainstem CMs compared with 1.6–3.1% among all CMs.<sup>[19,21,30]</sup> Like other CMs, prior hemorrhage of a brainstem CM has been the best predictor of future bleeding, with re-bleed rates from 5% to 35% per year.<sup>[1,30,51]</sup>

Surgical resection of brainstem CMs is generally considered after two or more symptomatic hemorrhages.<sup>[19]</sup> Lesions under surgical consideration ideally approach the pial surface as to minimize disruption of normal neural tissue. Historically, the surgical approach of choice has been guided by the two-point method described by Brown *et al.* and modified to disrupt the least amount of normal brain tissue.<sup>[5]</sup> In this method, a straight line is drawn from the center of the lesion to the periphery where it most closely reaches the pial surface, and then extended straight toward the skull. The area encompassed by the line generally dictates the surgical approach.

Based on the two-point method, a variety of skull base approaches may be used to access the entire perimeter of the brainstem. We believe that utilization of the endoscope, in place of the standard operating microscope, improves upon the well-established surgical approaches to brainstem CMs by minimizing trauma and improving visualization. Here we present a series of four brainstem CM resections employing endoscopy as the primary visualization, magnification, and illumination tool, as well as a review of the literature of endoscopic-assisted approaches to brainstem lesions. Combined, the four cases in our series demonstrate that the endoscope can be employed to access most regions of the brainstem.

## CASE I: MIDLINE VENTRAL PONS

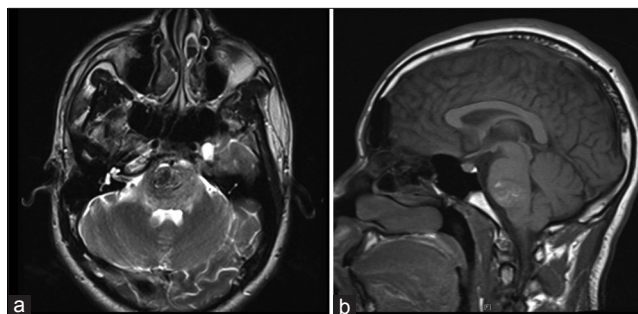
### History and clinical presentation

The patient is a 17-year-old male who presented with headache and right-sided facial numbness. Upon further workup, magnetic resonance imaging (MRI) demonstrated a lesion in the ventromedial pons consistent with a CM. The decision was made to observe the lesion given one symptomatic hemorrhage. However, over the ensuing 3 weeks, he experienced 2 additional episodes of neurological decline involving left hemiparesis, dysphagia, and right 6<sup>th</sup> cranial nerve palsy.

### Intervention

Given three symptomatic hemorrhages over 3 weeks, the decision was made to pursue surgical resection. The lesion measured 2.1 × 1.7 cm in the largest cross section and presented closest to the surface at the ventromedial pons near the midline [Figure 1]. Using the two-point technique, an endoscopic, endonasal, transclival approach was employed for a direct working angle and to improve visualization. Details of this case are presented elsewhere.<sup>[45]</sup>

A 2 surgeon, four-handed technique was used to perform the approach and resection. The sellar floor and basion marked the superior/inferior limits of the bony exposure, and the petrous portion of the internal carotid arteries bilaterally marked the limits of the lateral bony exposure. A midline durotomy was created and extended to the right where there was minimal discoloration of the brainstem. Stereotaxy was used to confirm the location of the lesion. A corticectomy was made and blood products expelled from the cavity [Figure 2]. The CM was resected in a piecemeal fashion, and a developmental venous anomaly (DVA) was identified and preserved. Autologous fascia lata from the patient's right thigh and nasoseptal flaps were used to reconstruct the defect. Postoperative imaging demonstrated complete resection of the cavernoma, preservation of the associated DVA, and wide resection of the clivus limited by the carotid arteries [Figure 3].



**Figure 1: Preoperative axial T2-weighted MRI demonstrating pontine cavernous malformation (a). Sagittal T1-weighted MRI demonstrating the same lesion (b)**

The patient's left hemiparesis had worsened in the immediate postoperative period, as had the right-sided facial weakness. He had vertical nystagmus and restricted horizontal gaze bilaterally. He was ultimately discharged but presented one month from surgery with cerebrospinal fluid (CSF) rhinorrhea and taken back to the operating room for re-exploration and revision of nonadherent nasoseptal flaps. A ventriculostomy catheter was placed, and an endonasal revision was performed using autologous abdominal fat graft, the previously fashioned nasoseptal flaps, fibrin glue and Avitene (Davol, Warwick, RI). The ventriculostomy catheter was used for CSF drainage for an additional 5 days and subsequently removed. At 2 years follow up, his strength and ocular symptoms had improved considerably, although he continued to have mild residual deficits.

## CASE 2: POSTEROLATERAL MIDBRAIN

### History and clinical presentation

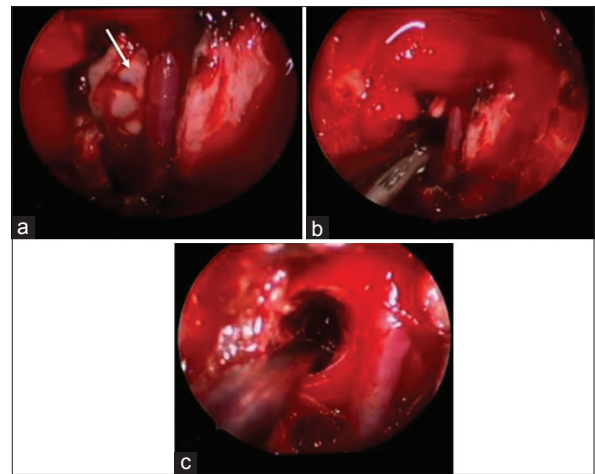
The patient is a 39-year-old female who presented to the emergency room with acute-onset of headache, double vision, and right-sided numbness. Head computed tomography (CT) revealed hemorrhage in the dorsal midbrain and she was admitted to the intensive care unit for observation. During the first evening of her hospitalization, she developed an acute change in mental status with CT evidence of progression of hemorrhage. Clinically, she was somnolent, had difficulty focusing her gaze and had a trace right pronator drift. Subsequent MRI demonstrated a lesion measuring  $1.8 \times 1.3$  cm in the largest cross section consistent with a CM and hematoma located primarily in the left dorsal midbrain extending anteriorly to the left cerebral peduncle and inferiorly to the left middle cerebellar peduncle [Figure 4].

### Intervention

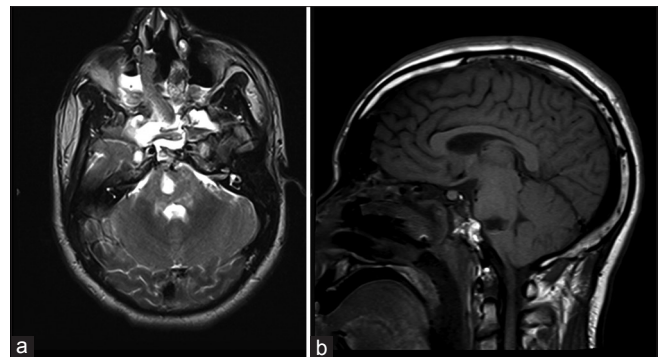
Given progression of hemorrhage on 3 serial CT scans and 2 symptomatic hemorrhages within 3 days, the decision was made to proceed with surgical resection. She underwent a retrosigmoid craniotomy with an endoscopic lateral supracerebellar-infratentorial (SCIT) approach.

The patient was placed in the lateral position. A large, sigmoid-shaped incision was fashioned behind her ear and a 3-cm retrosigmoid craniotomy created. The dura was opened exposing the retrosigmoid area for approach to the cerebellopontine angle (CPA). Using the 2.7 mm endoscope (Karl Storz, Tuttlingen, Germany), the cerebellomedullary cistern was opened to drain CSF.

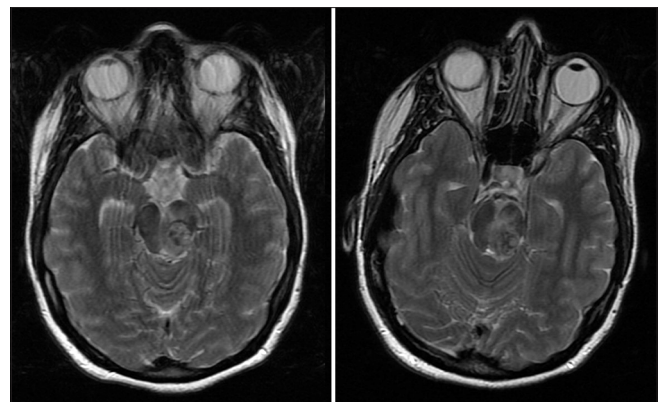
The endoscope was then inserted along the tentorium, taking care to identify, cauterize, and divide bridging veins. The Mitaka pneumatic holding arm (Mitaka Kohki, Tokyo, Japan) was used to stabilize the endoscope, and standard bimanual techniques were used to dissect the arachnoid



**Figure 2: Endoscopic view of surgical field.** View of basilar artery and hemorrhagic staining of pons (arrow) (a). Expulsion of blood products following pial opening (b). Surgical cavity following resection of cavernous malformation (c)



**Figure 3: Postoperative axial T2-weighted MRI (a). Postoperative sagittal T1-weighted MRI (b)**



**Figure 4: Preoperative axial T2-weighted MRI demonstrating a left posterolateral midbrain cavernous malformation**

adhesions. The 4<sup>th</sup> cranial nerve was identified and followed to its origin at the midbrain. The arachnoid over the tentorial edge on the lateral aspect of the midbrain was opened, exposing hemorrhagic staining of the leptomeninges on the lateral midbrain immediately under the tentorium and above the 4<sup>th</sup> cranial nerve [Figure 5a].

A significant amount of blood clot was evacuated with suction and bipolar electrocautery. Next, a round knife was used to dissect the capsule of the lesion and cupped forceps were used to resect the malformation [Figure 5b]. After hemostasis was obtained, the dura was closed primarily with interrupted sutures, and a muscle autograft was placed over the dural closure. Collagen allograft was placed over the muscle, and gelfoam was placed over the allograft. The bone flap was replaced and augmented with a titanium mesh cranioplasty.

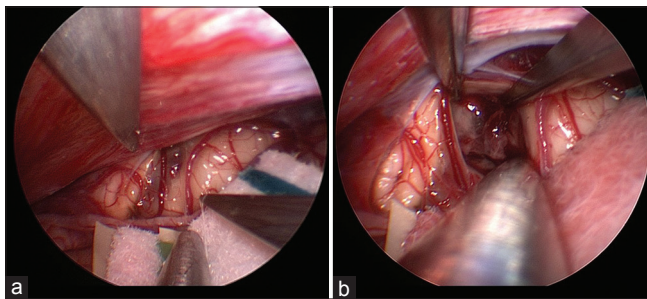
Postoperatively the patient remained at her neurologic baseline. Postoperative MRI showed no evidence of residual lesion [Figure 6]. The patient's mental status continued to improve, although she continued to have diplopia and sensory dysfunction. She was discharged to home within several days of surgery.

At one year follow up, she continued to have numbness of the right arm and leg without weakness. She had intact extraocular movements, and her diplopia had resolved.

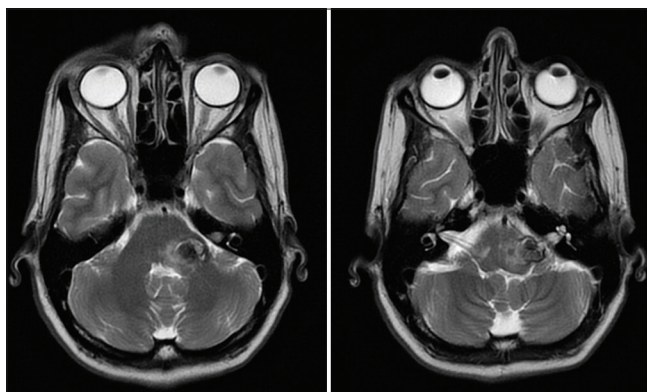
### CASE 3: LATERAL PONTS

#### History and clinical presentation

The patient is a 59-year-old female who developed hearing loss in the left ear approximately 4 weeks



**Figure 5:** Endoscopic view of surgical field demonstrating hemorrhagic staining of the left posterolateral midbrain (a); Resection of the cavernous malformation following pial opening (b)



**Figure 7:** Preoperative axial T2-weighted MRI demonstrating a cavernous malformation of the left posterolateral pons adjacent to the cranial nerve VII/VIII complex

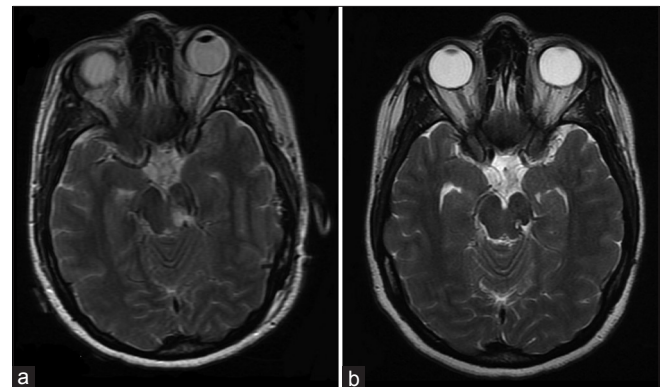
prior to presentation. Three weeks after the onset of symptoms, she also developed left facial paresis and was referred to a neurologist. MRI demonstrated a heterogeneous lesion measuring  $1.8 \times 1.4$  cm in the largest cross section with mixed-age blood products and hemosiderin ring consistent with a CM of the left pons, adjacent to the root entry zones of the 7<sup>th</sup> and 8<sup>th</sup> cranial nerves [Figures 7 and 8].

On initial neurosurgical evaluation, she had diminished hearing in the left ear and a House–Brackmann grade 3/6 left facial palsy with preserved ability to close her eye. She also had decreased left facial sensation. She maintained an intact gait with normal balance.

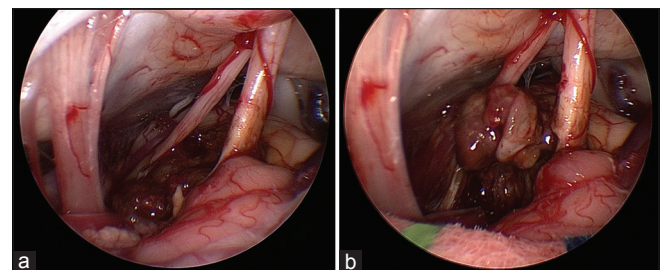
#### Intervention

Given the progression in symptoms from hearing loss to facial paresis over several weeks, the decision was made to proceed with surgical resection.

The patient was placed in a lateral position and a sigmoid-shaped incision was fashioned behind her ear. A 3-cm retrosigmoid craniotomy was created. Both the 3D Visionsense intraoperative miniature microscope (Visionsense, New York, NY) and the 2.7 mm endoscope were used, stabilized with the Mitaka pneumatic holding arm. The cerebellomedullary cistern was opened under endoscopic visualization to facilitate drainage of CSF. The 7<sup>th</sup> and 8<sup>th</sup> nerve complex



**Figure 6:** Axial T2-weighted MRI immediately postoperatively (a), and at 6 months postoperatively (b)



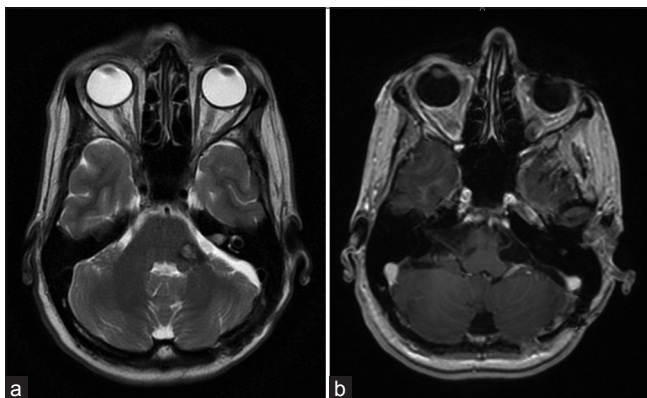
**Figure 8:** Endoscopic view of the surgical field demonstrating hemorrhagic staining of the left posterolateral pons (a), and dissection of the lesion between the 7<sup>th</sup> and 8<sup>th</sup> cranial nerve complex (b)

was identified. Subsequently, the 5<sup>th</sup> nerve complex and petrosal vein were identified. Old hematoma and staining was seen on the 8<sup>th</sup> nerve, tracking proximally to the pontine surface at the root entry zone of the 8<sup>th</sup> nerve [Figure 8a].

Normally the 7<sup>th</sup> nerve sits directly deep to the 8<sup>th</sup> nerve during the retrosigmoid approach, however, in this case the 7<sup>th</sup> nerve was separated from the 8<sup>th</sup> nerve at the root entry zone by the CM. The anterior inferior cerebellar artery was dissected off of the cerebellum, which allowed access to the lesion. Bipolar electrocautery was used to gently access the lesion, at which point the encapsulated CM was encountered. Gentle pressure expelled old blood products. A combination of bipolar electrocautery and round knife was used to dissect the lesion [Figure 8b]. The most difficult area to achieve resection was in the lateral aspect of the CM, as a retractor was not used on the cerebellum. The lesion was resected until what appeared to be normal brainstem tissue was encountered. Hemostasis was achieved and the dura closed primarily with interrupted sutures. The bone flap was replaced and the wound closed in standard fashion.

Unfortunately, the patient's facial paralysis progressed to a House–Brackmann grade 6/6 postoperatively, and she had lost all hearing on her left side. Immediate postoperative MRI did not show definite residual CM and confirmed the preservation of an associated DVA.

In subsequent months, she underwent a gold weight procedure to protect her left eye, as well as facial re-animation procedures, which has led to some improvement in her facial function. Her 6-month follow up MRI, however, did show evidence of residual CM in the superior aspect of the cavity [Figure 9a]. At 18 months follow up, the residual CM was stable on MRI and she remained clinically unchanged. The patient elected not to undergo repeat surgery.



**Figure 9:** Six month postoperative MRI, axial T2-weighted demonstrating residual CM (a), T1-weighted with contrast demonstrating preserved DVA (b)

## CASE 4: MIDLINE VENTRAL MEDULLA

### History and clinical presentation

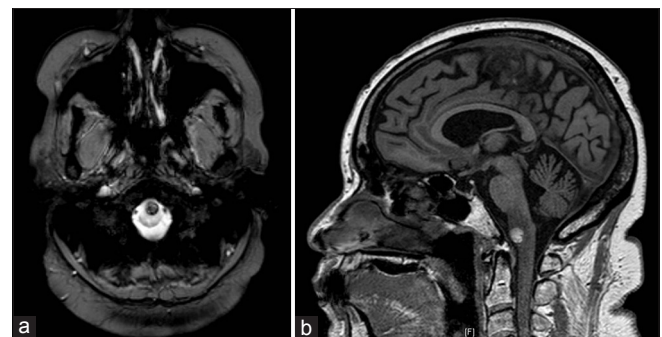
The patient is a 60-year-old female with a history of a medullary brainstem glioma treated with radiation 11 years prior to presentation. Eight years following radiotherapy, she was treated with chemotherapy for neurological deterioration thought to be due to recurrence. She then experienced mild stepwise decline in neurological function culminating in an abrupt right hemiparesis rendering her wheelchair-bound. The patient's neurological examination was remarkable for 2/5 right deltoid weakness and less severe distal right upper extremity weakness. Her right lower extremity demonstrated 2/5 muscle strength throughout. She continued to have good strength on her left side, and her cranial nerves were intact.

An MRI was obtained and demonstrated a well-circumscribed, nonenhancing hemorrhagic lesion in the region of the tumor that appeared to be consistent with a radiation-induced CM. The lesion measured 8 × 9 × 10 mm and presented closest to the surface at the ventromedial cervicomedullary junction [Figure 10].

### Intervention

Given the patient's history and symptoms, the decision was made to pursue surgical resection. Using the two-point method, an endoscopic, endonasal, transclival approach was employed.

A 2 surgeon, four-handed technique was used to perform the approach and resection. Bone from the middle of the clivus down to the ring of C1 was removed using a high-speed drill. The location of the C1 arch was confirmed with both stereotactic guidance and intraoperative X-ray. A narrow, midline bony channel was then drilled to expose the dura anterior to the medulla. The exposure was widened bilaterally but remained medial to the occipital condyles. The apical ligament of the odontoid process was removed to continue the



**Figure 10:** Preoperative axial gradient echo sequence MRI (a) and sagittal T1-weighted MRI (b) demonstrating a ventral medulla cavernous malformation

exposure inferiorly to the foramen magnum. A midline durotomy was fashioned inferior to the level of the basilar artery. A region of discoloration was noted on the pial surface [Figure 11a] and a small pial opening was made eccentric to the left of midline.

Necrotic tissue herniated from the pial opening, and a capsule was subsequently identified and removed en bloc using a cupped forceps [Figure 11b]. The cavity was inspected with no obvious tissue requiring further resection. Fat and autologous fascia lata from the patient's right thigh, septal bone, and vascularized nasoseptal flaps were used to reconstruct the defect. Postoperative imaging demonstrated resection of the lesion [Figure 12].

The patient's symptoms remained unchanged in the immediate postoperative period and at 3-month follow up.

## DISCUSSION AND REVIEW OF THE LITERATURE

Brainstem CMs are challenging entities but can be cured with gross total resection. Given the eloquence of the nearby neural tissue, symptomatic hemorrhages tend to present fairly dramatically followed by periods of improvement. This step-wise course continues as repeat hemorrhages occur. On the other hand, some brainstem CMs have a relatively benign course and may go completely unnoticed throughout one's life. Hence the risk and benefits of surgical resection over the natural history need to be carefully weighed prior to any surgical intervention. Preoperative planning to maximize the chance of complete resection is paramount, as subtotal resection has been shown to result in repeat hemorrhage rates of 62%.<sup>[20]</sup> Among our patients, we offer surgery after 2 symptomatic hemorrhages.

With any brainstem lesion, we try to choose an approach that provides adequate visualization of the entire lesion, minimizes brain retraction, and provides the working angles needed for complete resection with little disruption to the adjacent parenchyma. Approaches to brainstem CMs generally start with the two-point rule, in which a line is drawn from the center of the lesion to the point where the lesion comes closest to the surface

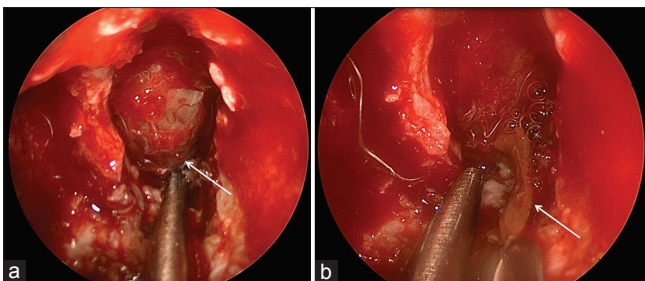
of the brain.<sup>[5]</sup> This line is then extended to the skull to guide the location of the craniotomy. While this method is a good starting point, there are unique challenges to brainstem CMs that require modification of the ultimate approach. Other tenets of brainstem CM surgery include entering the lesion via "safe entry zones," where anatomic knowledge of various brainstem tracts and nuclei are used to plan pial entry, preserving associated DVAs in order to prevent venous infarctions, and minimizing injury to the surrounding gliotic tissue.<sup>[10,33,41]</sup>

### The "Minimization" of brainstem CM surgery

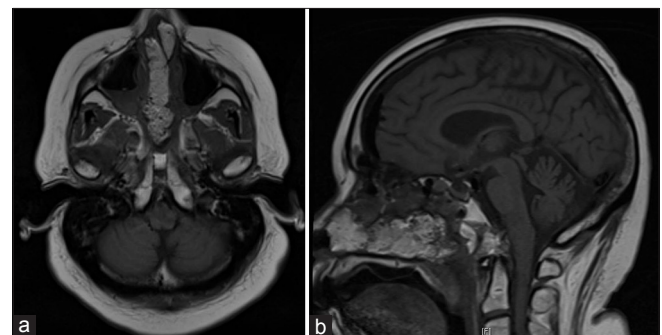
There have been many series published on brainstem CMs using varying surgical approaches. Spetzler and colleagues were the first to describe the "minimization" of surgical approaches to brainstem CMs by largely abandoning the skull base approaches with the highest morbidity, such as the transpetrosal and subtemporal approaches.<sup>[2,3,17]</sup> They described five primary approaches that can be used to access most brainstem CMs:

- SCIT approach – posterior or posterolateral midbrain
- Orbitozygomatic approach – anterior and anterolateral midbrain, interpeduncular region, ventral pontomesencephalic junction, rostral ventral pons
- Midline suboccipital with or without telovelar approaches – dorsal pons, floor of the fourth ventricle, dorsal cervicomedullary junction
- Retrosigmoid approach – lateral and posterolateral pons, CPA, lateral middle cerebellar peduncle, rostral lateral medulla
- Far lateral approach – inferolateral pons, anterolateral medulla.

Aside from limiting the types of craniotomies and associated skin incisions, recent literature has focused on minimizing the pial incision used to access the CM. Mai *et al.* have described their operative technique utilizing diffusion tensor imaging and neuronavigation to guide a small pial incision with subsequent piecemeal resection of the CM.<sup>[31]</sup> Chen *et al.* also used neuronavigation, but advocate for the use of local neurostimulation to detect



**Figure 11: Endoscopic view of surgical field demonstrating hemorrhagic staining in the medulla (arrow) (a) and removal of capsule (arrow) (b)**



**Figure 12: Postoperative axial T1-weighted MRI (a), sagittal T1-weighted MRI (b) demonstrating resection of the lesion**

cranial nerve nuclei, and specifically limit pial incisions to 1 cm.<sup>[8]</sup> Both groups used neurophysiologic monitoring during cases. However, as Mai *et al.* acknowledge, such small surgical windows make gross total resection difficult or even impossible to achieve.

### Applying endoscopic techniques

Given these challenges, we propose that the use of the endoscope can complement the above techniques by limiting the degree of bony resection and minimizing pial openings because the endoscope does not require large working spaces, can improve deep illumination and provides a panoramic view of the surgical cavity compared with the operating microscope.

Briefly, endoscopic approaches in intracranial surgery were primarily based in the treatment of hydrocephalus, and in the 1990s were largely applied to resection of pituitary lesions via transsphenoidal approaches.<sup>[6,26]</sup> Expanding on established techniques, neurosurgeons were able to apply endoscopy for the transventricular biopsy of tectal lesions, to fenestrate quadrigeminal arachnoid cysts and resect CPA lesions such as acoustic neuromas and epidermoid tumors.<sup>[16,32,35,47]</sup> While initial case reports largely described “endoscopically assisted” approaches, in which the endoscope was not used for the majority of the case, these clinical series, in combination with cadaveric studies demonstrating the utility of endoscopic approaches in traditionally open surgical approaches (e.g., far lateral and retrosigmoid approaches),<sup>[7,24]</sup> led to increased attempts at “fully endoscopic” cases. For example, Shahinian *et al.* presented three patients with fully endoscopic resections of acoustic neuromas and a more recent retrospective series by the same group reviewed 527 fully endoscopic acoustic neuroma resections and found a gross total resection rate of 94%, further bolstering the utility of the technique.<sup>[49,50]</sup>

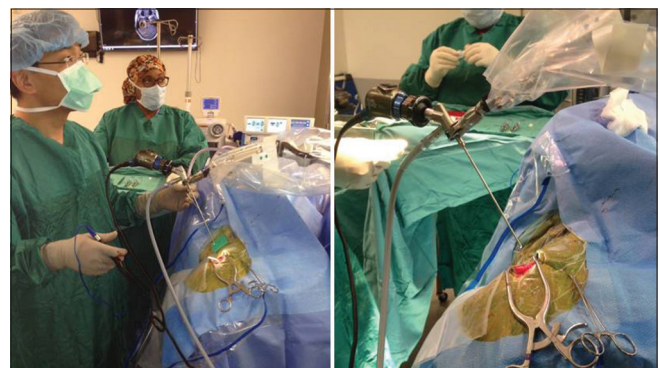
The specific use of the endoscope in surgery on CMs dates back to a 1994 case report by Otsuki *et al.* describing a frontal approach transcortical, endoscopic resection of a subthalamic region CM.<sup>[36]</sup> Sandalcioğlu *et al.* subsequently published their series of microsurgical resection of brainstem CMs followed by endoscopy to confirm resection and evaluate for hemostasis, although resection did not involve the endoscope.<sup>[46]</sup> While their study indicated a low rate of long-term new postoperative deficit (1/12), 1 patient needed to be taken back to surgery and 3 patients required shunts. In 2008, Prat *et al.* described transventricular resection of an intraventricular CM, the approach and technique being similar to those required for endoscopic resection of a colloid cyst.<sup>[39]</sup> In 2011, Ochalski *et al.* described a transcerebellar, endoscopic port resection of a right middle cerebellar peduncle hemorrhagic CM. While the above series are valuable in encouraging neurosurgeons to adopt the endoscope, it should be noted that endoscopic

resection of the CM all involved traversing normal neural tissue and may be argued whether they represent the optimal form of minimally invasive surgery.<sup>[34]</sup> In our series, we employed surgical corridors that did not require using retractors or traversing normal neural tissue.

For endoscopic endonasal procedures at our institution, the ear, nose, and throat (ENT) surgeon performs the approach and then moves to the patient’s left side and works through the left nostril, while the neurosurgeon simultaneously stands on the patient’s right side and works through the right nostril. Both surgeons operate with 2 hands. The ENT surgeon generally controls the endoscope, allowing the neurosurgeon to use both hands for dissection. In the retrosigmoid and supracerebellar/infratentorial approaches, the neurosurgeon operates alone using 2 hands for dissection. The endoscope is stabilized by the Mitaka pneumatic holder [Figure 13], which is anchored to the side of the operating table facing the anesthesiologist.

In both of the endonasal, transclival procedures described, exposure and cavernoma resection were performed purely endoscopically, without the use of the operating microscope. For the retrosigmoid and supracerebellar/infratentorial procedures, standard loupe magnification was used for exposure and dural opening, but the endoscope was the sole magnification tool used to approach and resect the cavernoma. While the mini-operating microscope was briefly brought into the field to compare visualization during the retrosigmoid craniotomy, the endoscope was found to provide a superior view and was therefore solely used for the rest of the procedure. It should be noted that unlike an endoscope with instrument ports, such as that used for an endoscopic third ventriculostomy, we used standard microsurgical instruments for removing the CM.

Our technique for resection of the CM itself is similar to that described by Mai *et al.*<sup>[31]</sup> Once the appropriate anatomy has been exposed, the first step is to identify hemorrhagic pial staining, which indicates the presence



**Figure 13:** The endoscope, stabilized by the Mitaka pneumatic holding arm, allowing the surgeon to operating using with both hands

of an underlying lesion. The next step is to perform the corticectomy, enter the CM, and internally debulk retained blood products. From within, the lesion is coagulated and shrunk using the bipolar electrocautery until the margin of the lesion is encountered, at which time we attempt to identify the capsule. If a capsule is encountered, we dissect the capsule in order to navigate the perimeter of the CM. In the event that a capsule cannot be clearly identified, the CM may be removed completely piecemeal until normal appearing neural tissue is encountered. While we generally use the latter method in noneloquent cortex, we prefer to identify the capsule whenever possible in the brainstem as removal of even small amounts of normal tissue may have devastating consequences. It should be noted, however, that the pathology is not in the capsule itself. In all procedures, the CM was dissected under fully endoscopic visualization using tapered Fukushima suction (Integra LifeSciences; Plainsboro, NJ) and stainless steel dissectors, and removed using cupped forceps or standard pituitary forceps. Abla *et al.* have also suggested that the CO<sub>2</sub> laser may be a useful adjunct for brainstem CMs in select cases.<sup>[3]</sup>

### Ventral pontine and medullary lesions

Regarding the anterior midline pontine and medullary lesions in our series, we pursued a novel endoscopic, endonasal, transclival approach. We have described this approach previously and a similar approach was described by Kimball *et al.*<sup>[28,45]</sup> Open approaches to these difficult lesions have included the presigmoid,<sup>[23]</sup> transpetrosal (intradural and extradural),<sup>[15,51]</sup> lateral transpeduncular,<sup>[25]</sup> and the retrosigmoid approaches.<sup>[4,40]</sup> While these approaches allow access to the anterolateral brainstem, they fail to adequately visualize lesions that are near the ventral midline surface. Additionally, some of the above approaches have largely been abandoned due to extensive bone drilling, and retraction and manipulation of vital nerves and vascular structures. For example, the transpetrosal approaches sacrifice hearing, which can be avoided with alternative approaches.

While anterolateral approaches to ventral, medial brainstem lesions continue to be employed, there is a large risk of postoperative motor deficits due to pyramidal tracts.<sup>[3]</sup> However, given a CM's displacement of normal neural tissue, safe resection is possible if the pial surface is approached from a midline anterior approach. This approach has been described in the literature by Reisch *et al.* describing a transoral, transclival technique.<sup>[42]</sup> However, this approach has a high risk of infection and CSF leak.<sup>[19]</sup> Likewise, the first transclival approach in our series was complicated by postoperative CSF leak requiring reoperation. While nasoseptal flaps and improved sealants have reduced the rate of CSF leaks, they are not fail-safe and the above patient required revision of his initial surgery in addition to a ventriculostomy catheter to correct

his CSF rhinorrhea.<sup>[22,27]</sup> Conversely, the second transclival case did not experience a postoperative CSF leak, although we did employ a more comprehensive closure. In the future, we will give consideration to prophylactic CSF drainage if there is any concern for a postoperative CSF leak, which may improve long term health-related quality of life if it prevents a reoperation.

Finally, a major challenge associated with both of these cases was obtaining the appropriate reach with the endoscopic tools employed, as most endoscopic instrumentation at this institution were designed for the removal of sellar lesions. Longer instrumentation will likely be beneficial in the future.

While the endoscopic, endonasal transclival approach has potential to resect ventral pontine and medullary lesions, it is critical that the surgeon have significant experience with the relevant anatomy, endoscopic techniques and instrumentation, and a plan to prevent potential postoperative CSF leaks.

### Lateral midbrain lesion

A direct midline approach is useful for approaches to the quadrigeminal plate and pineal region,<sup>[9,16,18,48,52]</sup> but we employed a lateral SCIT approach to this lesion given its paramedian location in the midbrain. De Oliveira published a series of 45 patients with brainstem CMs using the SCIT approach with microsurgical techniques, demonstrating clinical stability or improvement after resection of the brainstem CM compared with preoperatively in 88% of patients at a mean of 20 months follow up, providing some evidence of the safety of the technique.<sup>[11]</sup> Uschold *et al.* described an endoscopic SCIT approach to pineal region lesions in 9 pediatric patients, also demonstrating good results.<sup>[52]</sup> The value of the endoscope lies in the panoramic view afforded by the endoscope, deep illumination without the need for illuminated surgical instruments, and minimization of brain retraction. We did not find any difficulty maneuvering our instruments or the endoscope in the tight space between the tentorium and the cerebellum, and the visualization was excellent.

Another major benefit of the SCIT approach is the possibility of extending the approach to resect lesions via a transtentorial approach.<sup>[12]</sup> This allows one to approach medial temporal lobe lesions as well. Although this is not a brainstem location, it is an eloquent area in a difficult to reach location, and we believe the endoscope provides value as it brings the light source and camera close to the operative field, allowing the surgeon to work ergonomically.

### Lateral pontine lesion

A direct retrosigmoid approach was used to resect the lateral pontine lesion. While this approach can be routinely performed with either a microscope



or endoscope, the benefit of the endoscope is that extended approaches can potentially be exploited. For example, Samii *et al.* originally described a suprameatal extension of the retrosigmoid craniotomy, which can be useful to resect lesions extending through Meckel's cave into the antero-medial middle fossa.<sup>[44]</sup> Additionally, Ebner *et al.* have recently described the benefits of an endoscope-assisted approach to the ambient and interpeduncular cistern through this approach.<sup>[14]</sup> We believe the use of extended retrosigmoid techniques in combination with an endoscope will be further utilized in the future with good results. One notable challenge with this approach is when using angled endoscopes for visualization around turns. The instrumentation associated with angled endoscopes needed to dissect and perform surgery is currently limited, but we believe that with time additional tools that provide sufficient dexterity will be developed.<sup>[29]</sup>

## CONCLUSION

We have described a series of 4 brainstem CMs resected using endoscopic techniques. The endonasal, transclival approach is a technique that we believe provides the most direct approach to midline anterior pontine and medullary lesions. In other regions of the brainstem, the endoscope serves as an adjunct to standard open approaches in order to limit craniotomy size, minimize brain retraction and improve visualization. However, surgeon experience and skill in endoscopic techniques are a high priority before embarking on these approaches, and further refinements in endoscopic tools and techniques are necessary for them to become standard of care.

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