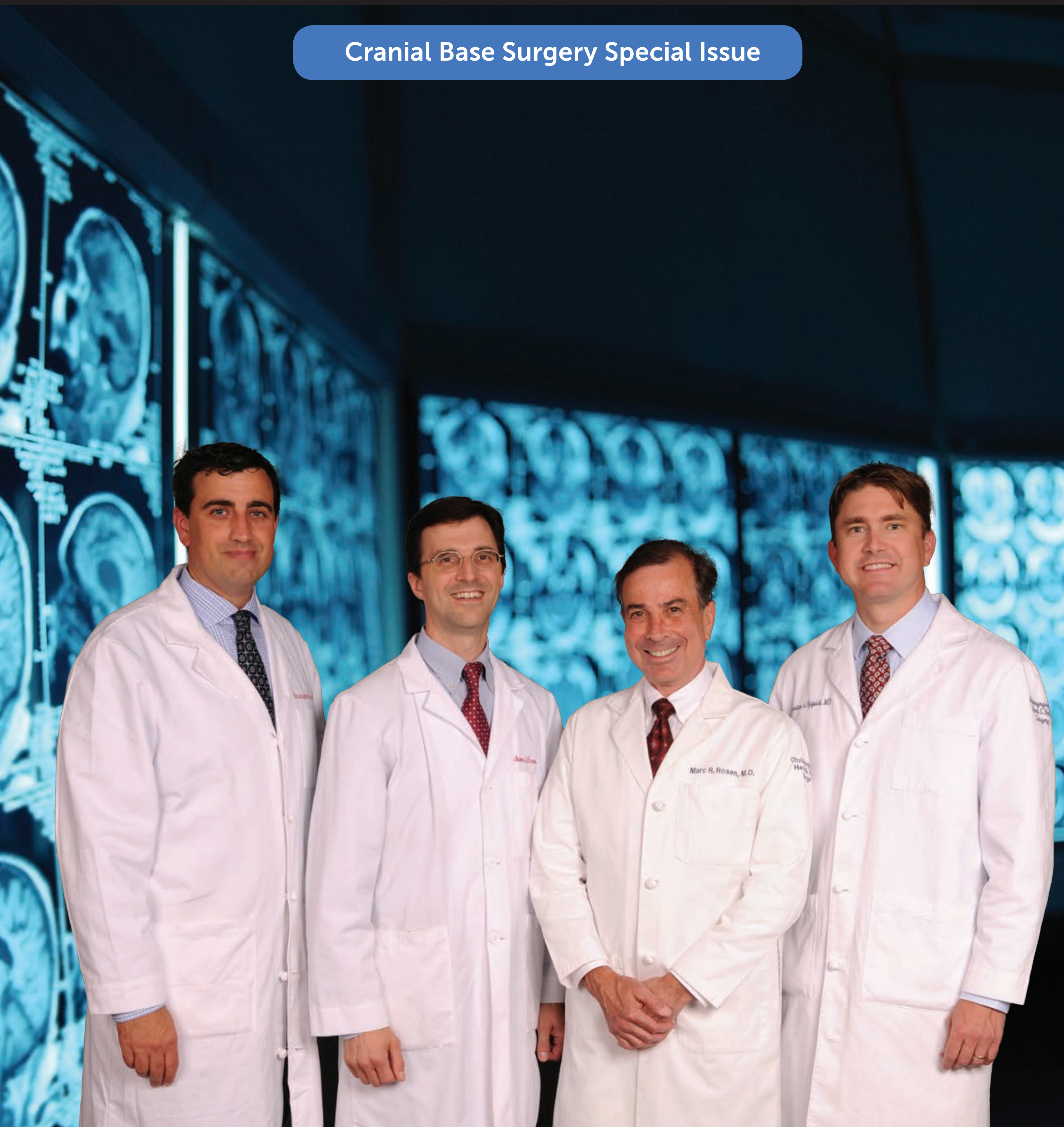
VOL 10, ISSUE 2 | FALL 2015

# JHN JOURNAL

a publication of Thomas Jefferson University, Department of Neurological Surgery

## Cranial Base Surgery Special Issue



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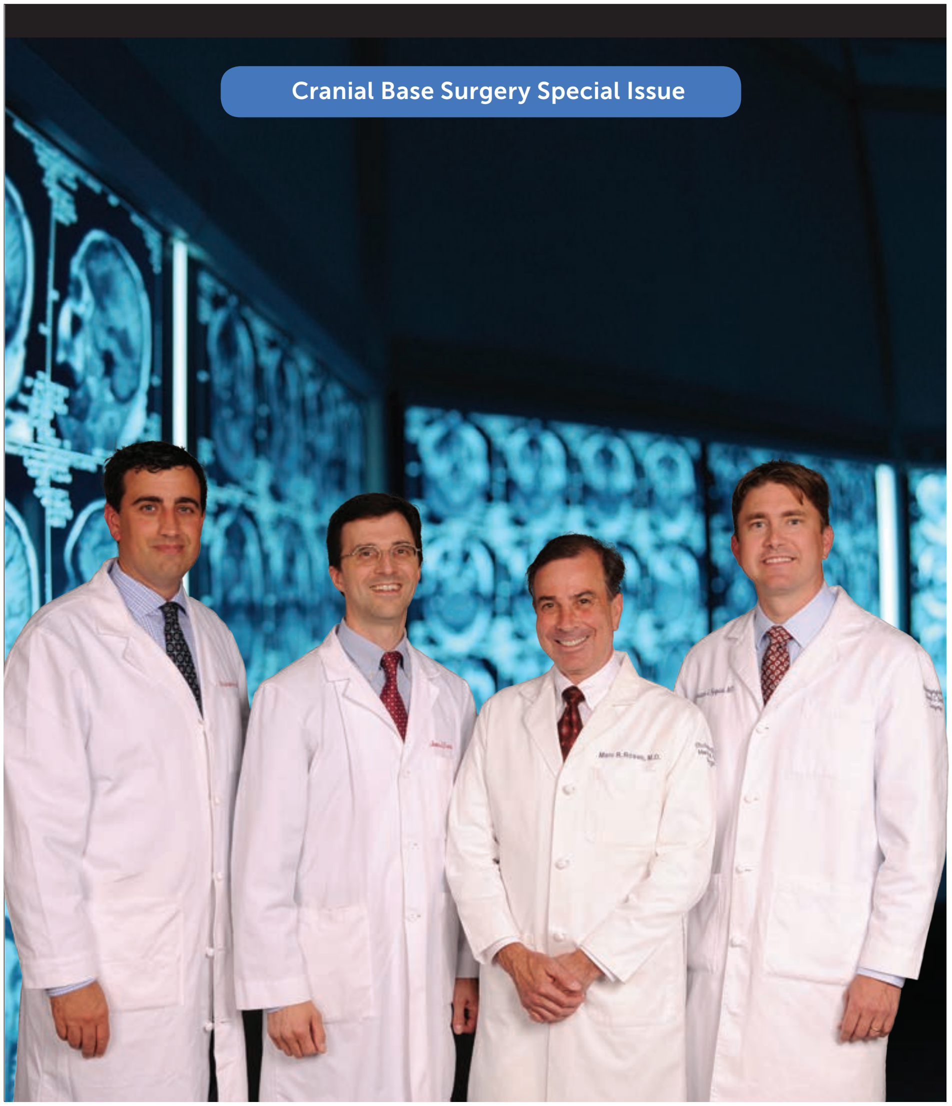


A publication of Thomas Jefferson University, Department of Neurological Surgery



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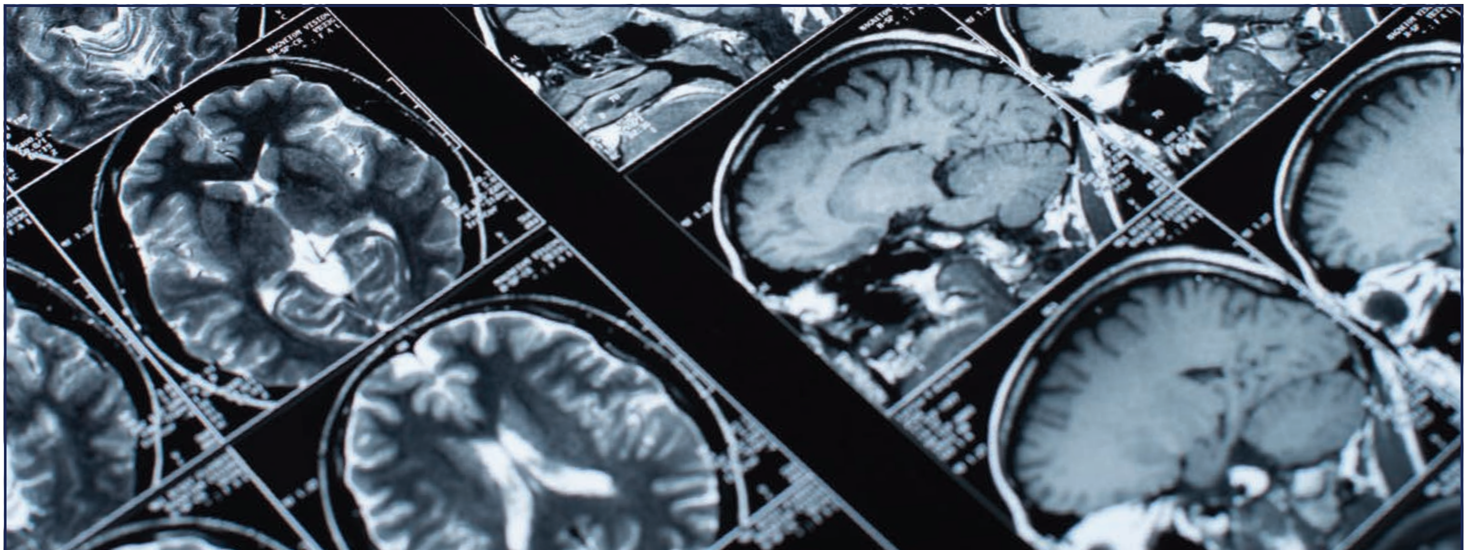
# JEFFERSON MINIMALLY INVASIVE CRANIAL BASE SURGERY & ENDOSCOPIC NEUROSURGERY CENTER

The Jefferson Minimally Invasive Cranial Base Surgery & Endoscopic Neurosurgery Center was officially established in 2008 as the first dedicated minimally invasive endonasal program in the Delaware Valley. However, the endonasal surgery effort actually began in 2004 as a joint collaboration between cranial base surgeons in the Departments of Neurological Surgery and Otolaryngology. The program rapidly expanded to provide comprehensive multi-disciplinary care for patients with pituitary tumors, meningiomas, sinonasal malignancies, orbital tumors, meningoencephaloceles, chordomas, craniopharyngiomas, and many other cranial base disorders. As pioneers in endoscopic skull base surgery, the Center's faculty members are recognized nationally and internationally as experts in the field and have been committed to educating other physicians in the emerging field of minimally invasive endonasal surgery. In addition to their efforts while serving on the executive committees of the North American Skull Base Society and AANS/CNS Joint Section on Tumors, the Center's faculty highlights include their establishment of complimentary accredited fellowship programs in Neurosurgery and Otolaryngology, organization and participation in endoscopic skull base training courses throughout the world, role in creating guidelines for the surgical treatment of pituitary tumors, and authorship of the definitive comprehensive text on management of craniopharyngiomas.

The Center currently features four dedicated state-of-the-art endoscopic surgical suites, each equipped with the most advanced optics and computer navigation systems. Jefferson surgeons have helped lead the development of the micro-instrumentation specific to endoscopic neurosurgery and continue to advance the field through the development and refinement of surgical approaches and study of patient outcomes using these less invasive techniques. The establishment of a tumor bank repository for the study of these relatively rare tumors has allowed for new understanding of the metabolic derangements driving pituitary tumor growth and identification of molecular targets for the treatment of these challenging disorders. Non-surgical treatments are also provided by the Center including Gamma Knife stereotactic radiosurgery and stereotactic radiotherapy. The Jefferson physicians helped develop fractionated stereotactic radiation therapy techniques that have revolutionized the way tumors located near radiation-sensitive structures, such as the nerves for hearing and vision, are successfully treated without injury to these critical structures.

This special edition of the *JHN Journal* highlights the joint collaboration between the Departments of Neurological Surgery and Otolaryngology and provides a sampling of the clinical research performed at the Jefferson Center for Minimally Invasive Cranial Base Surgery & Endoscopic Neurological Surgery Center.



# Cranial Base and Endoscopic Endonasal Surgery Fellowship

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## How to apply:

Please contact Janice Longo **(janice.longo@jefferson.edu)** for an application.

Eligible candidates will have successfully completed an accredited neurosurgery residency, be eligible for a Pennsylvania medical license and be able to provide at least three letters of recommendation. International medical graduates must have successfully passed USMLE Steps I, II and III.

For additional information on the fellowship, please visit the North American Skull Base Society (http://www.nasbs.org/nasbs-skull-base-fellowship-registry/cranial-base-endoscopic-endonasal-surgery-fellowship)

**The Department of Otolaryngology also offers a one-year Rhinology & Skull Base Fellowship. Please visit the American Rhinologic Society for additional details on the fellowship and applicationprocess (https://www.amercan-rhinologic.org/jefferson)*

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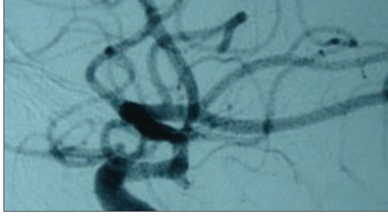

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# Fully Endoscopic Microvascular Decompression for Trigeminal Neuralgia

Christopher J. Farrell, MD[1]; Hyunwoo Do, MD[1]; Sonia Geschwindt, MD[1]; James J. Evans, MD[1,2]

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Trigeminal neuralgia (TN) is a chronic, progressive facial pain disorder characterized by severe paroxysmal episodes in the distribution of the trigeminal nerve. The most common cause of (TN) is compression of the trigeminal nerve by a vascular structure within the posterior fossa at the dorsal root entry zone (DREZ). Initially described by Dr. Peter Janetta, microvascular decompression has been clearly demonstrated to be a safe and effective treatment for TN with excellent immediate and long-term pain relief.[1]

Although neuroimaging has advanced significantly allowing for improved pre-operative visualization of the trigeminal nerve and determination of vascular conflict, most neurosurgeons continue to practice the MVD procedure in a very similar manner to Dr. Janetta's 1967 description.[2] While the retrosigmoid craniotomy and operative microscope allows for an excellent view of the posterior aspect of the trigeminal nerve within the cerebellopontine angle, visualization of the anterior aspect of the nerve is limited. Additionally, adequate visualization of the DREZ may be difficult and require additional retraction of the cerebellum, potentially resulting in complications such as hearing loss and cerebellar injury. As neurosurgical experience with the endoscope has grown, a variety of authors have described performing microvascular decompression with endoscopic assistance which involves using the endoscope to inspect the trigeminal nerve for sites of compression but performing the decompression under the microscope. While the main advantage of the endoscopic approach compared to the microscopic approach is improved visualization of the trigeminal nerve from the DREZ to Meckel's cave including its inferior, anterior and superior surfaces, evolution of the procedure to a fully endoscopic approach has the additional benefits of being less invasive with minimal soft tissue dissection and cerebellar retraction allowing for reduced patient discomfort and accelerated recovery. In this technical review, we describe our approach to performing a fully endoscopic microvascular decompression including the surgical nuances that allow the procedure to be performed safely and efficiently.

## SURGICAL PLANNING AND INSTRUMENTATION

The indications for the fully endoscopic MVD do not differ from those of the microscopic approach. However, surgical instrumentation varies considerably beyond use of the endoscope. While the asterion represents an

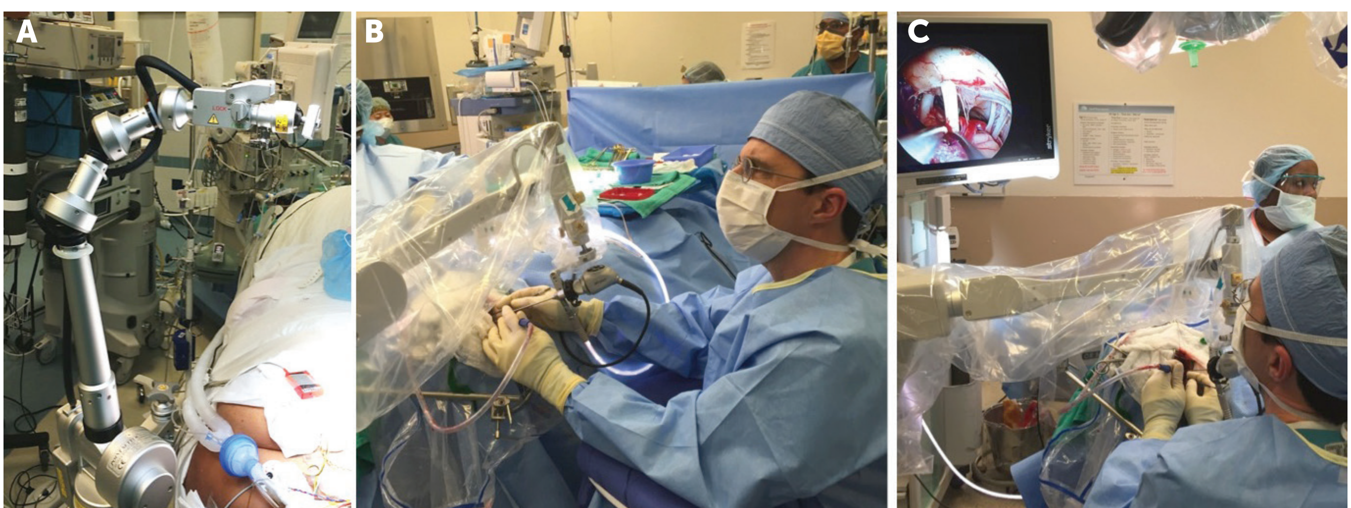


**Figure 1**

**A.** The pneumatic endoscopic holding arm is fixed to the contralateral side of the OR table prior to draping. **B.** The holding arm and 2.4mm endoscope are positioned parallel to the posterior petrous ridge. **C.** The endoscope is placed along the tentorium and fixed proximal to the internal auditory canal allowing instruments to be brought into the field above and below the endoscope.

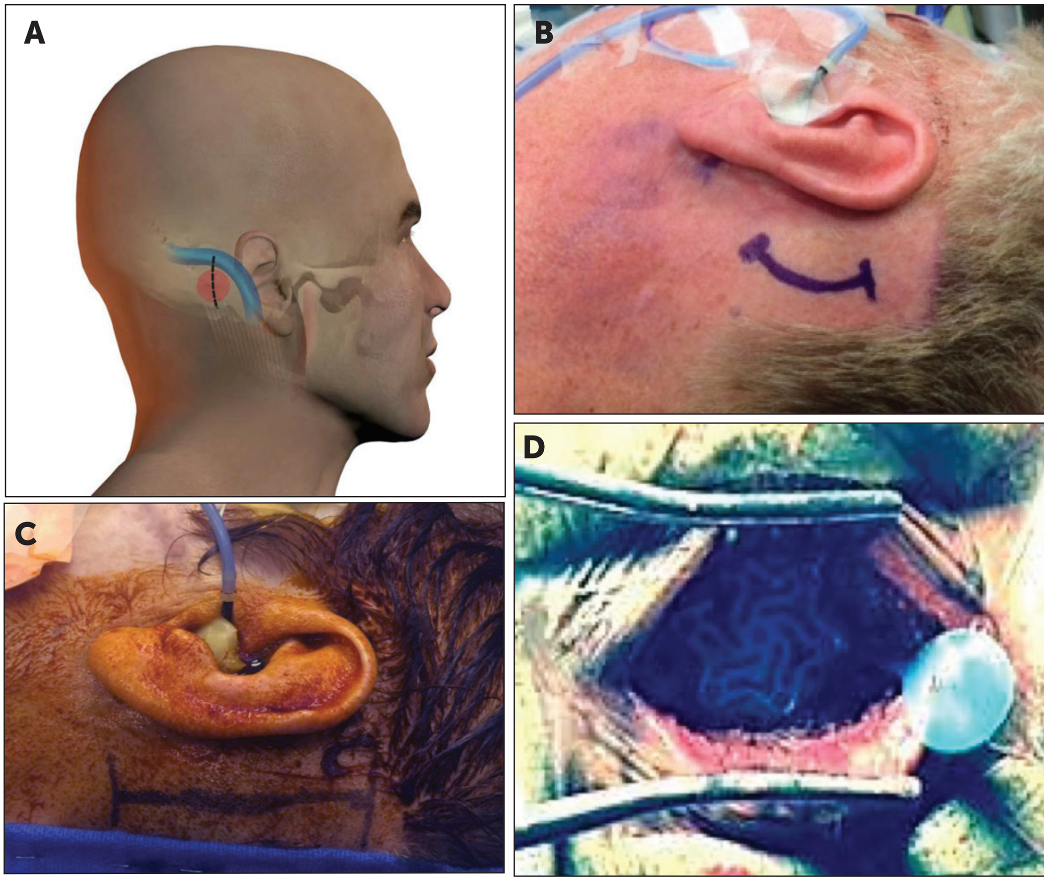


**Figure 2**

**A.** Illustration of placement of the incision (dotted line) and bony opening (shaded area) relative to the transverse and sigmoid sinuses. **B.** Slightly curvilinear 2cm incision is planned for endoscopic MVD, which is significantly reduced in length compared to our standard microscopic MVD incision **(C)**. **D.** The bony opening for the endoscopic MVD is made to be the same size as a 14mm burr-hole cover.

important landmark for any retrosigmoid craniotomy, we prefer to also utilize image-guidance during the fully endoscopic approach as accurate placement of the incision is critical to perform the procedure is a truly minimally-invasive manner. Additionally, we utilize bipolars (SILVERGlide Bipolar Forceps, Stryker, Kalamazoo MI) with ultra-thin tines of variable lengths that enable increased maneuverability when working through small craniotomies and bayonetted, rotating microdissectors (Evans Rotatable instruments, Mizuho America Inc., Union City, CA) designed for endoscopic use. Although dynamic endoscopy is extremely helpful in establishing depth of field and is the preferred technique for endonasal endoscopy, the restricted anatomy of the cerebellopontine angle lends itself better to fixed endoscopy. Although several endoscopic holders are commercially available, we have utilized the Mitaka holding arm (Mitaka Kohki Co., Tokyo, Japan) which is OR-table mounted with multiple joints and pneumatically controlled, allowing for one-handed manipulation (Figure 1). We typically begin the procedure using a 4mm, 0-degree rigid endoscope (Karl Storz, Tuttlingen, Germany) that is attached to the holder arm. However, if access is limited, we not infrequently utilize a pediatric 2.4mm rigid endoscope to increase our working area for bimanual dissection. Angled endoscopes (30-degree, 70-degree) are employed as necessary. A high-definition camera and monitor are critical for performance of the fully endoscopic approach as safe dissection of the arachnoid is contingent upon subtle visual cues. Although obscuration of the endscope lens may occur, we do not utilize an endoscope lens cleaner during this procedure as this device increases the circumference of the endoscope and further restricts working area. We have found that gentle intermittent irrigation of the endoscope by the assistant effectively restores image quality.

## INCISION AND CRANIOTOMY

We typically perform an approximately 2cm linear or curvilinear retroauricular incision enabling placement of a 14mm diameter burr hole-type craniectomy at the sigmoid-transverse junction (Figure 2). In patients with thicker skin and musculature, the curvilinear incision is preferred as the slight posterior extension does not allow the soft tissue and self-retaining retractor to restrict the angle of the endoscope along the posterior petrous bone. If instrumentation optimized for endoscopic utilization is not available, we recommend using a slightly increased craniectomy size of approximately 18mm. Minimal muscular disruption is performed due to the more superior location of the craniotomy and a self-retaining retractor or stay-sutures can be used to retract the skin edges. The burr hole is drilled with a 6mm-round cutting bit providing approximately 2mm of exposure of the inferior aspect of the transverse sinus and posterior aspect of

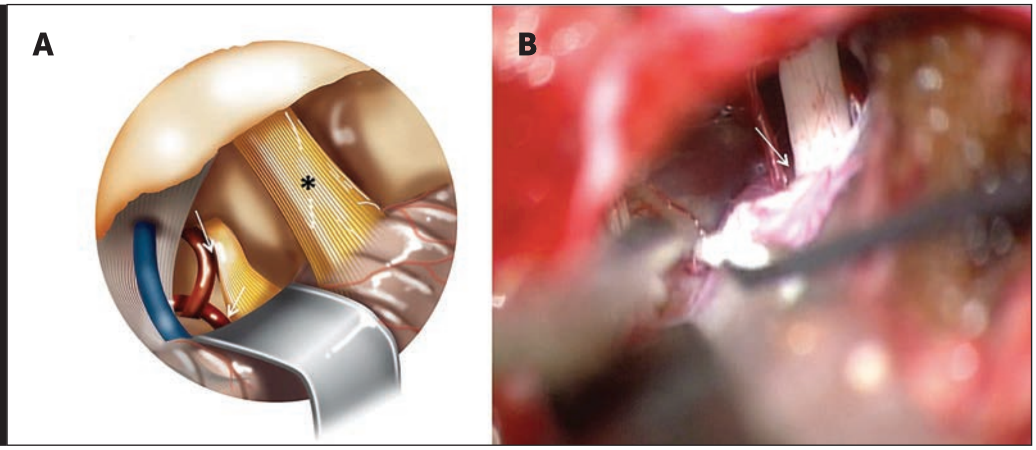


**Figure 3**

**A.** Illustration of the positioning of the endoscope proximal to the cranial nerve VII/VIII complex (*), allowing for view of the trigeminal nerve root entry zone and sites of potential vascular compression (arrows) **B.** Endoscopic view of trigeminal nerve and site of vascular compression at nerve root entry zone (arrow).

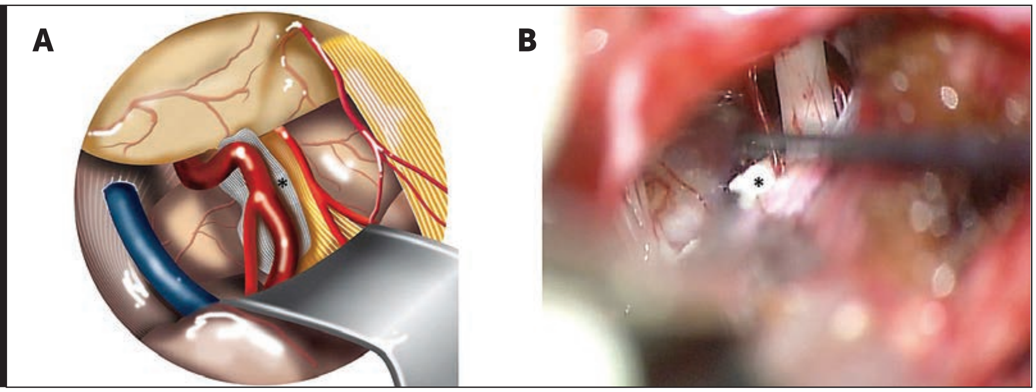


**Figure 4**

**A.** Illustration of placement of PTFE (Teflon) pledget (*) between trigeminal nerve and compressing artery **B.** Endoscopic view with bimanual manipulation of pledget.

the sigmoid sinus. Failure to adequately remove bone over the sinuses will limit the final positioning of the endoscope and may necessitate increased cerebellar retraction.

## EXPOSURE AND DECOMPRESSION OF THE TRIGEMINAL NERVE

The dura is then opened in a C-shaped fashion extending from the transverse sinus edge to the sigmoid sinus edge followed by a bisection of the dura toward the sigmoid-transverse sinus junction. The dural leaflets are then retracted with stay-sutures. Similar to the skin incision, the posterior opening of the dura over the cerebellum allows the endoscope to be inserted with increased degree of freedom and to achieve the optimal angle for visualization and instrument maneuverability. The supero-lateral aspect of the cerebellum is then gently retracted and the endoscope advanced into the cerebellopontine angle along the tentorium under endoscopic visualization. As access to the cisterna magna is not possible, temporary placement of a fixed retractor may be necessary at this point to allow for the arachnoid above the cranial nerve 7/8 complex to be sharply dissected and cerebrospinal fluid gently aspirated to facilitate cerebellar relaxation. The trigeminal nerve is then inspected from the DREZ to Meckel's cave for any sights of vascular compression with the 0-degree and angled endoscopes dynamically (Figure 3). At this point, the fixed cerebellar retractor is removed and the endoscope repositioned to its optimal location, typically along the tentorial edge allowing for instruments to be passed more inferiorly. No further cerebellar retraction is necessary throughout the procedure, although sacrifice of the superior petrosal vein is frequently necessary to achieve optimal positioning of the endoscope. Placement of the endoscope along the posterior petrous face allows for an excellent view of the inferior aspect of the trigeminal nerve but requires a more oblique angulation of the endoscope that restricts maneuverability. Additionally, the endoscopic view may be compromised by a prominent suprameatal tubercle. The lateral cerebellar surface is covered with a rubber dam to allow for easy repetitive introduction of instruments without incurring cerebellar surface injury. Although cottonoids can serve a similar function, their thickness can prove obtrusive during this minimally invasive approach. Similar to the microscopic approach, bimanual manipulation of the trigeminal nerve and offending artery is then performed with buffering of the nerve with a small piece of polytetrafluoroethylene (Figure 4). Once the decompression has been performed, circumferential inspection of the trigeminal nerve should be repeated with angled endoscopes to ensure no further areas of compromise, including the DREZ, prior to endoscope removal.

## DURAL AND BONY RECONSTRUCTION

Similar to the microscopic approach, careful attention to dural closure is important to prevent post-operative cerebrospinal fluid leakage, however, with the endoscopic approach, the dura can typically be repaired primarily as there is no thermal injury to the dura. The craniectomy site is inspected for any air cells and waxed appropriately followed by reconstruction with a 14mm titanium burr hole cover plate (Figure 1).

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# Management and Surveillance of Frontal Sinus Violation following Craniotomy

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## INTRODUCTION

Complications related to frontal sinus violation during craniotomy procedures are often significantly delayed and under-recognized by surgeons. Retrospective studies with long-term follow up data, however, have estimated that up to 10% of these patients can have long-term sequelae related to disruption of the frontal sinus, most commonly in the form of delayed mucocele formation.[1] The true incidence of mucocele formation after frontal sinus violation is unknown and likely partially depends upon the degree of involvement of the frontal sinus outflow tract. While there is no universally accepted method for management of these patients once infection or outflow obstruction has occurred, standard practices include endoscopic marsupialization or Lothrop procedure, obliteration of the frontal sinus, and cranialization.

This study analyzes nine patients at this institution with a history of frontal sinus violation after craniotomy and subsequent development of mucoceles. In addition, we performed a meta-analysis via a PubMed search using the search terms "frontal sinus mucocele", "frontal craniotomy complication", and "frontal sinusitis."

## MATERIALS AND METHODS

Patients in the case series all presented to Thomas Jefferson University Hospital between 2005 and 2014 with a mucocele after a frontal sinus violation via a craniotomy. Surgical management was performed by our skull base team, consisting of a neurosurgeon and otolaryngologist. In addition, we performed a meta-analysis via a PubMed search using the search terms "frontal sinus mucocele", "frontal craniotomy complication", and "frontal sinusitis."

Review of the literature revealed 2,763 results with only four manuscripts meeting our inclusion criteria examining frontal sinus mucocele formation after craniotomy.

## RESULTS

Retrospective analysis revealed nine patients at our institution with a history of frontal sinus violation and subsequent mucocele formation. The average time from the initial frontal sinus violation to presentation at our clinic was 15.1 years (range 3 – 36 years), with most patients presenting with headache symptoms (Table 1). All of the mucoceles were addressed via an endoscopic, endonasal approach except one patient who developed lateral orbital and frontal bone osteomyelitis with subdural empyema and required craniotomy for debridement and frontal sinus repair. This patient had previously undergone an "eyebrow" approach craniotomy with violation of the anterior and posterior lateral walls of the frontal sinus with titanium reconstruction of the anterior wall (Figure 1). Frontal sinusitis developed 10 years after the craniotomy and endoscopic frontal sinusotomy failed to relieve the lateral infection. The patient subsequently underwent a craniotomy with complete cranialization and exenteration of the frontal sinus with vascularized pericranial graft reconstruction.

Review of the literature yielded four articles with 27 patients that were suitable for inclusion in our meta-analysis. Meetze et al[2] reported their findings of delayed frontal sinus mucocele formation in six patients. Indications for the initial frontal sinus violation were skull base tumors, aneurysm, craniofacial deformity, arteriovenous malformation, and fungal sinusitis. The average time from craniotomy to mucocele presentation was 14.8 years (range 1- 39 years). Yoshioka[3] also presented six patients with average time from craniotomy to presentation of 20.7 years. Chandra et al[4] reviewed a series of patients who underwent a frontal sinus obliteration and later developed mucoceles. Schramm et al[5] also reported two cases of mucocele formation after craniotomy. The average time interval between frontal sinus violation and frontal mucocele presentation for this meta-analysis was 13.3 years with a range of 4 months to 39 years.

## DISCUSSION

Frontal sinus mucoceles may arises from a variety of etiologies, with traumatic frontal sinus fracture or disruption via craniotomy representing two frequent precipitating factors. Any type of frontal sinus violation, however, can disrupt and entrap the mucosa leading to a mucocele. As the results of our study reveal, this process typically develops in a significantly delayed fashion, often more than a decade from the initial frontal sinus injury, making long-term surveillance extremely important and challenging.

The most effective means to prevent frontal sinus mucocele formation is to avoid entering the frontal sinus during the craniotomy. In the era of image guidance, surgeons are better able to delineate the anatomical boundaries of the frontal sinus and avoid this structure when possible. However, when the frontal sinus is disrupted either

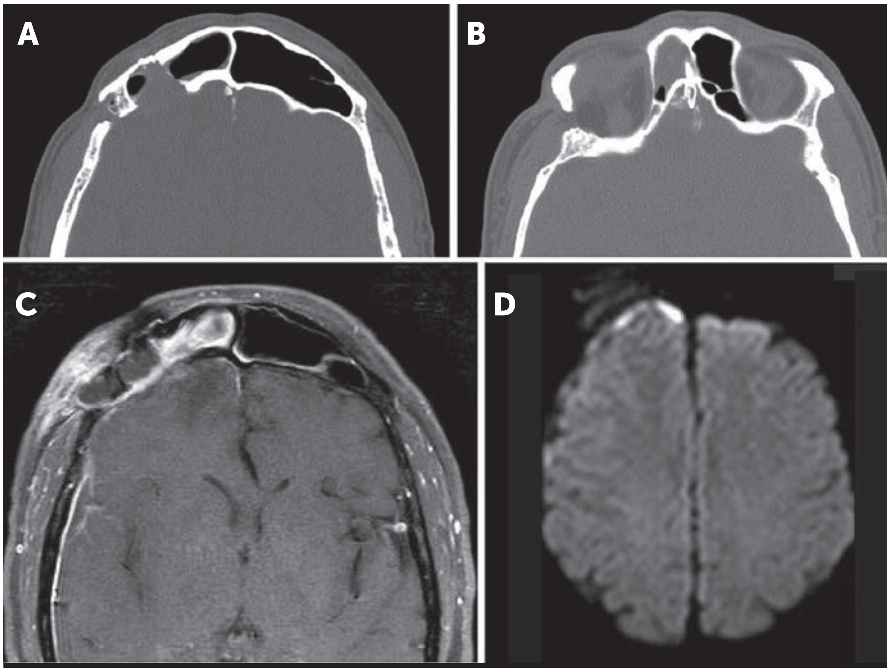


**Figure 1**

**A.** CT demonstrating violation of the anterior and posterior walls of the frontal sinus with lateral sinusitis and **B.** obstruction of the right frontal recess. **C.** Delayed MRI demonstrates worsening frontal sinusitis with leptomeningeal enhancement and **D.** subdural restricted diffusion indicative of empyema.

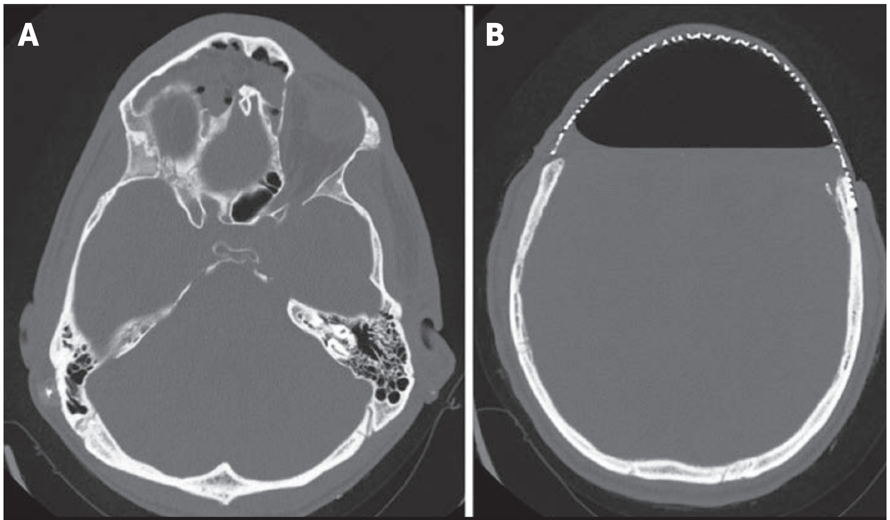


**Figure 2**

**A.** Postoperative CT demonstrating incomplete frontal recess obliteration with persistent aeration of the frontal sinus. **B.** CT showing resultant tension pneumocephalus.

purposefully or inadvertently, outflow obstruction of the frontal sinus must be avoided unless the entirety of the frontal sinus mucosa has been exenterated. Yoshioka[3] identified that each of his revision procedures for delayed mucocele formation occurred when the frontal recess had been "plugged" at the time of initial surgery with incomplete removal of the frontal sinus mucosa. He recommended management with complete cranialization of the frontal sinus and mucosal extenteration, followed by frontal sinus recess obliteration. Failure to fully obliterate the frontal sinus recesses allows for direct communication between the frontal sinus and intracranial cavity leading to postoperative pneumocephalus and likely infection (Figure 2). Overzealous obliteration of the frontal sinuses with large amounts of material such as adipose tissue is likely not necessary and makes surveillance of the frontal sinus more complicated and endonasal drainage of the frontal sinus more technically challenging should endoscopic drainage become necessary.

In the setting of small frontal sinus bony violation without mucosal disruption, extensive cranialization and exenteration of the mucosa is likely not necessary as the drainage pathway for the mucous secretion from the frontal sinus remains undisturbed. When the mucosa has been disrupted, careful reconstruction of the frontal sinus cavity will generally prevent long-term intracranial mucocele formation as long as the outflow pathways remain undisturbed. A vascularized pericranial graft represents the ideal reconstruction material although this material is not always available or viable at the time of closure. Reconstruction with hydroxyappetite or bone cement should be avoided as these materials have been associated with infection when employed in the region of the sinuses.[6]

There are a variety of options for the management of frontal sinus mucoceles. Most surgeons consider marsupialization via an endoscopic endonasal approach to be the procedure of choice as it has the least morbidity.[6] In our series, 8 of 9 patients were successfully treated with an endoscopic endonasal approach. The endoscopic endonasal approach may

Table 1. Patient Information

| Case No. | Age, Sex | Indication for Craniotomy | Years from Craniotomy | Presenting Symptoms | Recurrence | Follow-up period (months) | Treatment of Frontal Sinus Violation Following Craniotomy | Management of Frontal Sinus Pathology |
|---|---|---|---|---|---|---|---|---|
| 1 | 58, F | Crouzon Syndrome | 36 | Eye swelling, headache | No | 22 | None | Endoscopic Marsupialization |
| 2 | 72, F | Osteoma | 20 | Forehead swelling, nasal discharge | No | 8 | None | Endoscopic Marsupialization |
| 3 | 48, M | Brain Abscess | 20 | Postnasal drip, discharge | No | 6 | Cranialized | Endoscopic Marsupialization |
| 4 | 55, M | Unknown | 11 | Eye and eyelip swelling | Yes | 5 | None | Endoscopic Marsupialization |
| 5 | 71, F | Mucopyocele | 6 | Chronic frontal sinusitis | Yes | 73 | Cranialized | Endoscopic Marsupialization |
| 6 | 71, F | Optic Nerve Tumor | 3 | Periorbital pain, vertigo | Yes | 21 | None | Endoscopic Marsupialization |
| 7 | 38, M | Meningioma | 7 | Periorbital cellulitis | No | 24 | Cranialized | Failed Endoscopic Marsupialization; Cranialization and abscess drainage |
| 8 | 36, M | Frontal sinus fracture | 3 | Headache, frontal sinusitis | No | ** | Cranialized | Endoscopic Marsupialization |
| 9 | 53, M | Frontal sinus fracture | 30 | Proptosis and progressive loss of vision | No | 1 | None | Endoscopic Marsupialization |

be precluded if the mucocele is too far lateral above the orbit or if the frontal sinus has been obliterated by material that cannot be easily removed through the nose. Additionally, an endoscopic approach is contraindicated if there is neurologic tissue obstructing instrumentation of the frontal sinus or in the setting of brain abscess or other intracranial infection.

Mucoceles can develop decades after the initial frontal sinus violation. Our meta-analysis identified that the average time to presentation was 13.3 years with a range of 4 months to 39 years. In the setting of frontal sinus disruption at the time of craniotomy, long-term vigilance is necessary to detect complications. Delayed CT or MR imaging should be performed 10-15 years in this population with these recommendations paralleling those for surveillance of frontal sinus fracture repair.[7,8] Furthermore, follow up with an otolaryngologist performing nasal endoscopy and reviewing the imaging may help prevent complications from mucocele formation such as orbital and intracranial infection.

## CONCLUSION

Violation of the frontal sinus, either through craniotomy or fracture, can result in mucocele formation as an early or late sequela. Image guidance may help avoid unnecessary frontal sinus violation during a craniotomy. Mucoceles may develop decades after the initial frontal sinus violation and long term follow-up with imaging and an otolaryngologist is necessary to care for these patients. While the endoscopic endonasal approach is usually the preferred method to treat these lesions, obliteration or cranialization of the frontal sinus may be necessary in certain situations.

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# Endonasal Approaches Allowing Preservation of the Nasal Septal Flap: The Jefferson Classification

Gurston G. Nyquist, MD[1]; Seth E. Kaplan, MD[1]; D. David Beahm, MD[1]; Tyler J. Kenning, MD[2]; Christopher J. Farrell, MD[2]; Marc R. Rosen, MD[1,2]; James J. Evans, MD[1,2]

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**Key Words**

*pituitary, pituitary adenoma, transsphenoidal, endoscopic skull base, nasal septal flap*

## INTRODUCTION

The pedicled nasoseptal flap (NSF) is an excellent option for endoscopic repair of cranial base defects.[1-4] In certain cases, it is not clear whether a NSF flap will be necessary for repair of the cranial base at the start of the procedure. Even though not initially anticipated, the NSF may be required at the end of the case or future surgeries. Therefore, preservation of the NSF and its vascular pedicle is paramount.[4-6] The objective of this paper is to describe endonasal surgical techniques and approaches to the cranial base that will preserve the nasal septal flap and its vascular pedicle.

## METHODS AND RESULTS

We describe five approaches that allow sufficient cranial base exposure while preserving the NSF pedicle. All approaches provide protection for at least one pedicled NSF to be used for cranial base repair if needed.

## TECHNIQUE AND METHODS

### Unilateral approach

The unilateral approach utilizes only one nasal cavity to access the sphenoid sinus and sella. This one sided approach is defined by a wide unilateral sphenoidotomy for adequate access to the sella or lateral sphenoid sinus (Figure 1a,b). The contralateral nasal cavity is completely undisturbed, not only preserving the NSF pedicle, but also reducing nasal morbidity. This approach has limited applications and is best implemented for small pituitary lesions or accessing the lateral sphenoid sinus for encephalocele repair.

### "The 1 ½ approach": Ipsilateral wide sphenoidotomy with small contralateral sphenoidotomy and limited posterior septectomy

In this approach, a wide sphenoidotomy is performed usually on the right for a right-handed neurosurgeon. This may compromise the NSF vascular pedicle unless a 'rescue flap' is created. In this technique, the mucosa of the posterior septum and sphenoid rostrum is reflected inferiorly and the bone of the sphenoid rostrum is resected in a submucosal fashion in order to preserve the NSF. An additional limited contralateral (left) sphenoidotomy is then performed from the sphenoid os superiorly and laterally with care to preserve the vascular pedicle of the NSF located inferiorly. The sphenoidotomies are then connected by a limited posterior septectomy (Figure 2 a,b).

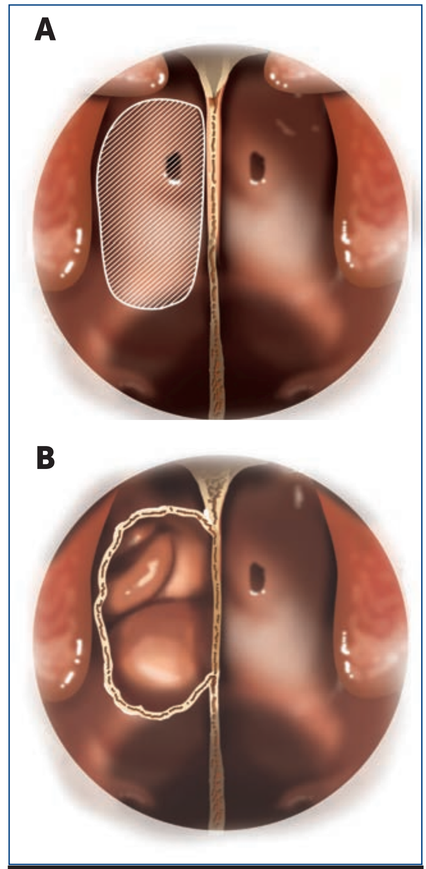

**Figure 1**

"Unilateral Approach" (A) Endoscopic view of both sphenoid ostium in the coronal plane. The shaded region represents the area of the sphenoidotomy for a unilateral approach (B). Endoscopic view of a unilateral approach after the sphenoidotomy with a view into the sphenoid sinus.

### Septoplasty with submucosal "tunnel" approach

In patients with nasal obstruction resulting from septal deviation or when surgical access is limited secondary to significant

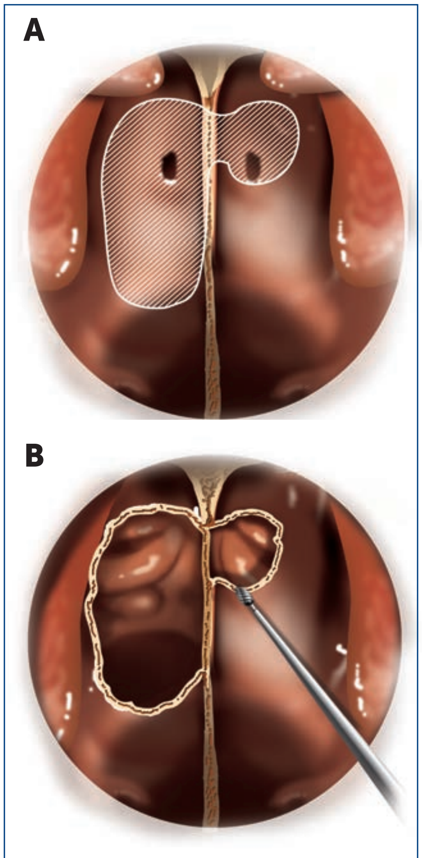


**Figure 2**

"The 1.5 Approach" (A) Endoscopic view of both sphenoid ostium in a coronal plane. The shaded region represents the area of where the sphenoid ostium are opened bilaterally in a 1.5 approach. (B). Illustration of the 1.5 approach after bilateral sphenoid sinusotomy with a view into the sphenoid sinus. The left sided sphenoidotomy is extended further for access than depicted here with care to preserve the NSF pedicle.

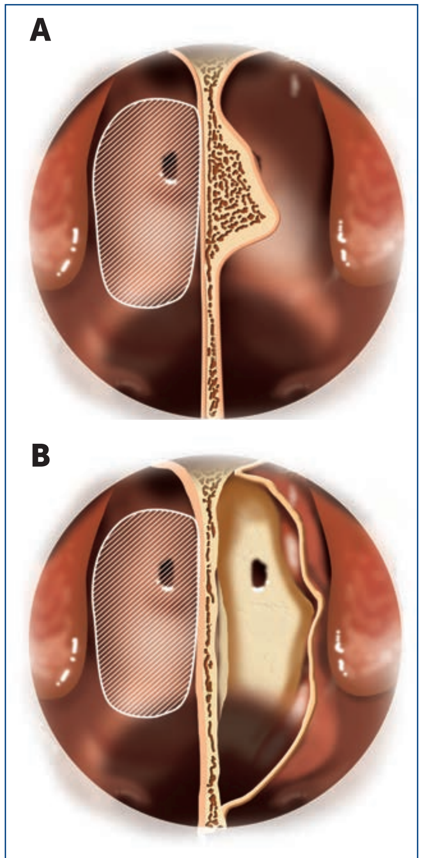


**Figure 3**

Tunnel Approach" (A) Endoscopic view of both sphenoid ostium in a coronal plane with a left sided septal spur. The shaded region represents the area of the right sphenoid sinusotomy. (B). The left septal spur has been removed and the left sphenoid ostium is visualized within the septal flap. A wide sphenoidotomy is created within the septal flap.

septal deflections or spur, a septoplasty is performed at the beginning of the case (Figure 3a). Working in the submucosal tunnel preserves the NSF and leaves the sinonasal cavity undisturbed on one side.

The approach begins with a standard hemitransfixion incision used for a septoplasty. The septal mucopericondrium and periostium is raised in the same manner as a septoplasty, and any septal deflections or spurs are corrected, and a sphenoidotomy is created within the flap (Figure 3b).

On the contralateral side to the hemi-transfixion incision, a wide sphenoidotomy is created. For example, if a left-sided tunnel is created, then an endonasal sphenoidotomy is made on the right side. Instruments are passed through the sphenoidotomy on the right and via the "tunnel" on the left.

### Septal mobilization and transposition

Septal mobilization and transposition is an approach that allows access to the midline anterior cranial base for pathology involving the olfactory groove where olfaction will be sacrificed (Figure 4). Rather than create a superior septectomy and the resultant post-operative septal perforation, the septum is mobilized and transposed during the case. A NSF is harvested and protected in the nasopharynx. A contralateral hemitransfixion incision is made the side of the lesion, and superior and inferior submucosal tunnels are raised. The remainder of the mucopericondrium and mucoperiosteum remains attached to the septal cartilage and bone between the superior and inferior tunnels. The septal cartilage is incised anteriorly leaving at least a 1 cm strut of anterior cartilage for nasal support. The remainder of the bony septum is cut superiorly at the skull base and inferior septal incisions are made, freeing the septum from the maxillary crest. The septum is then released from the sphenoid rostrum mobilizing the bony and cartilaginous nasal septum with at least the septal mucosa from one side, and the septum is transposed laterally. At the conclusion of the case the septum is relocated to the maxillary crest with no resultant septal perforation.

### Nasal septal flap harvest and replacement

Another approach to preserving the NSF is to harvest it at the beginning of the surgery and replace it onto the septum with sutures if it is not required for reconstruction.

## DISCUSSION

This manuscript describes endonasal cranial base approaches that will protect the NSF pedicle and retain the ability to utilize the NSF for reconstruction only if needed. This is an important concept as a very limited or even no CSF leak is encountered when resecting a pituitary tumor and placement of a NSF is not required. While relatively minor, the use of a NSF has potential morbidity such as excessive crusting, numbness, septal perforation, mucocele formation, and anosmia. Thus, the NSF should be used

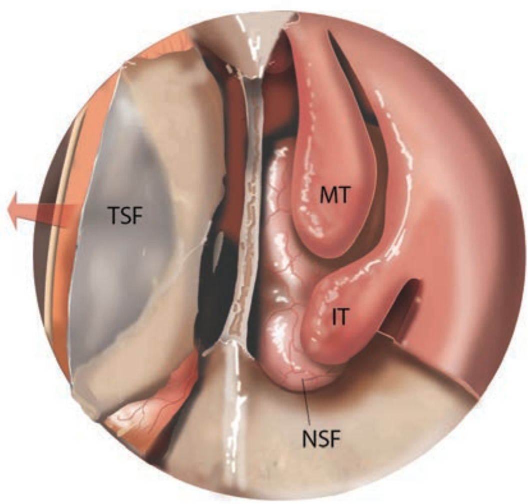


**Figure 4**

"Septal Mobilization" The left sided NSF flap has been raised and tucked away in the nasopharynx. Superior and inferior incisions are made mobilizing the septal cartilage. The cartilage is still attached to the right septal mucop-erichondrium, and is transposed to the right lateral nasal wall. This allows for access to the anterior cranial base. NSF, nasoseptal flap; MT, middle turbinate; IT, inferior turbinate; TSF, transposed septal flap.

judiciously but preserved for future use. Clinical outcomes and the feasibility of these approaches will be published in another manuscript.

Deciding which NSF preserving trans-sphenoidal approach to implement generally depends on the presence of a septal deflection and size of the skull base defect. Large anticipated intra-operative CSF leaks begin with harvesting a NSF while a NSF preserving approach is recommended when a CSF leak is unlikely. In the presence of a nasal septal deviation, the "tunnel" approach is generally implemented and the "1.5 approach" reserved for cases without a septal deflection.

## CONCLUSIONS

The nasoseptal flap is an important reconstruction option for skull base defects. We identify five approaches to endoscopic cranial base surgery that better protect both the pedicle of one or both nasal septal flaps while allowing adequate exposure of the cranial base for tumor resection. Utilizing our methods, endonasal surgeons should have at least one nasoseptal flap at their disposal as a means of repairing cranial base defects if needed.

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# Is Reconstruction of the Sella Necessary to Prevent Optic Chiasm Prolapse and Cerebrospinal Fluid Leakage Following Endoscopic Resection of Pituitary Macroadenomas?

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## INTRODUCTION

Visual compromise is a common presentation of pituitary macroadenomas and is related to direct optic nerve and chiasm compression. Although the extent of visual recovery following treatment depends on the duration and severity of the visual compromise, the majority of patients experience gradual improvement in their vision. Delayed visual deterioration following treatment is typically related to either tumor recurrence or radiation-induced optic neuropathy, although visual worsening due to prolapse of the optic apparatus into a secondary empty sella has rarely been reported. In 1968, Guiot reported the first a case of reversible visual deterioration associated with optic chiasm prolapse following resection of a large pituitary macroadenoma (Guiot). Based on their observations, Guiot and collaborators recommended that a "prop" be placed in the sella at the time of transsphenoidal pituitary adenoma resection to prevent progressive herniation of the optic structures. Similarly, Hardy coined the term "preventive chiasmopexy" to describe filling of the sella cavity with autologous tissue such as muscle or fat following resection of large tumors to prevent this herniation phenomenon. While optic chiasm prolapse with associated visual deterioration appears to represent a rare occurrence, its true incidence and pathophysiological basis remain uncertain. Reconstruction of the sella with autologous tissues is also widely employed as a means to prevent postoperative cerebrospinal fluid leakage with these tissues typically harvested from a secondary operative site such as the abdomen. Although not frequently reported in the pituitary literature, complications of abdominal fat graft harvest include hematoma and seroma formation as well as infection with an incidence ranging from 1-7%. At our institution, we do not routinely perform dural reconstruction following transsphenoidal resection of pituitary macroadenomas using adipose tissue to prevent cerebrospinal fluid leakage or optic chiasm prolapse. In this study, we sought to determine the incidence of optic chiasm prolapse into the sellar defect by determining the radiographic position of the optic chiasm following surgery and incidence of delayed visual deterioration.

## METHODS

A retrospective review was performed for 100 consecutive patients with pituitary macroadenomas who underwent transsphenoidal resection with postoperative clinical and radiographic data greater than 6 months from the date of initial surgery (Table 1). The position of the optic chiasm was determined on sagittal MRI and defined as the distance above a line constructed between the superior aspect of the tuberculum sellae and the dorsum sellae (Figure 1). The position of the optic chiasm was compared between the preoperative MRI and the available MRI most distant from the date of surgery. Visual data was obtained from the clinical record. Dural closure was performed using a synthetic dural substitute placed as an inlay graft under the dural defect and supplemented with a thin layer of dural sealant (Tisseel®, Baxter Healthcare; Duraseal®, Covidien)

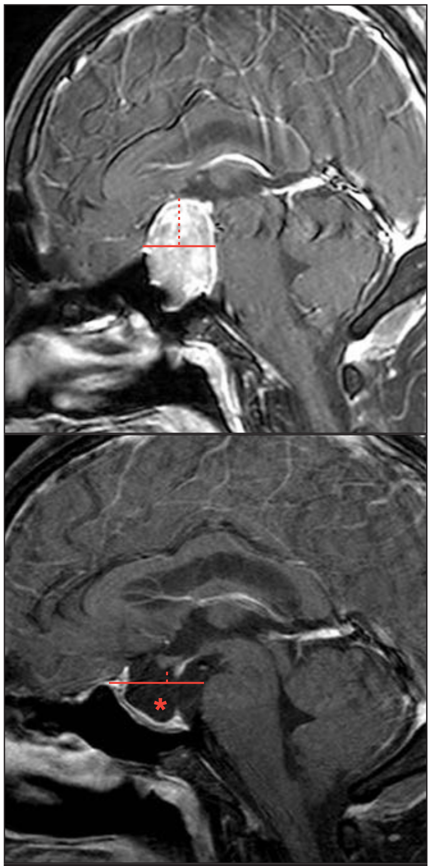

**Figure 1**

**Determination of Optic Chiasm Position**

**A.** Sagittal post-contrast MRI depicting preoperative distance of optic chiasm displacement (dotted line) by a pituitary macroadenoma relative to the superior aspect of sella turcica (solid line). **B.** Postoperative MRI showing return of optic chiasm to a more normal position (dotted line) without prolapse into the sellar defect (*).

**Table 1: Demographics**

| | Number of patients |
|---|---|
| Male | 56 |
| Female | 44 |
| Average Age | 54 ± 13 years (range 22-80) |
| Tumor type | |
| Non-secretory Adenoma | 86 |
| Prolactinoma | 2 |
| Growth Hormone Secreting Adenoma | 12 |
| CSF leak | |
| Intraoperative | 17 |
| Postoperative | 0 |

**Figure 2: Optic Chiasm Position**

| | Total | No preoperative Visual loss | Preoperative Visual loss |
|---|---|---|---|
| Average tumor size (mm) | 24.9 ± 10.2 | 18.5 ± 6.5 | 29.2 ± 10.1 |
| Average preoperative displacement of OC (mm) | 9.0 ± 5.9 | 6.2 ± 3.6 | 11.2 ± 6.7 |
| Postoperative position of OC (mm) | 3.0 ± 2.0 | 3.1 ± 2.0 | 2.6 ± 1.7 |

endoscopic transsphenoidal resection of pathologically demonstrated pituitary macroadenomas without packing of the tumor resection cavity using synthetic or autologous materials. Preoperative MRI demonstrated the presence of a macroadenoma with suprasellar extension in all cases with a mean tumor height dimension of 24.9mm (± 10.2) (Table 2). The average position of the optic chiasm preoperatively was 9.0mm (± 5.9) above the superior aspect of the sella turcica. The mean time between the date of surgery and postoperative MRI was 422 days (± 239). No patient reported delayed visual deterioration postoperatively and the mean position of the optic chiasm on postoperative MRI was 3.0mm (± 2.0) above the superior aspect of the sella. Despite the presence of a large intrasellar tumor resection cavity in all cases, inferior prolapse of the optic chiasm was observed on delayed postoperative MRI in only 1/100 cases and not associated with visual impairment.

Preoperative evaluations revealed that 57 patients complained of visual loss prior to surgery. Tumors reported to cause visual loss were significantly larger (29.2 +/- 10.0mm) than tumors that did not inhibit vision (18.5 +/- 6.5mm, $p<0.0001$), and the amount they displaced the optic chiasm (11.2 +/- 6.7mm) differed significantly from the amount of displacement caused by tumors that did not affect vision (6.2 +/- 3.6mm, $p<0.0001$). Of the patients with initial visual loss, 48 (84.2%) reported an improvement in their vision after surgery while 7 (12.28%) reported no change in their visual status. The amount of postoperative displacement of the optic chiasm in patients whose vision did not change postoperatively was not significantly different from that of patients who experienced visual improvement after surgery. At follow-up, no change in visual status was reported for any of the patients who were without visual deficiencies before surgery. No delayed visual worsening throughout the study period was observed. No patient developed a postoperative cerebrospinal fluid (CSF) leak, though 17 experienced intraoperative leaks.

## DISCUSSION

This study demonstrates that inferior prolapse of the optic apparatus into the sellar defect following transsphenoidal pituitary macroadenoma resection represents an extremely rare occurrence and placement of an intrasellar “prop” consisting of harvested autologous tissue is not necessary to achieve stable visual recovery. Our success, combined with the rarity of visual loss secondary to optic apparatus prolapse, lead us to reason that the risks of autograft outweigh its possible benefits.

### Pathophysiology of delayed visual loss

Since Guiot first introduced the concept of a “prop” to prevent delayed visual changes after macroadenoma resection, several groups have tested theories regarding the pathophysiology of this complication. Chiasmal scarring was present in the fifteen surgical cases in the literature (Czech 1999, Decker 1977, Fischer 1994, Thome 2004), and is mostly accompanied by displacement of the chiasm and optic nerves into the sella. In our practice, we have seen several cases of delayed visual deterioration secondary to shrinkage of giant pituitary prolactinomas with optic chiasm prolapse following prolonged dopamine agonist therapy (Figure 2). In all cases, the visual worsening has stabilized an ultimately improved following temporary cessation of dopamine agonist therapy and slight regrowth of the prolactinoma and return of the chiasm to a more normal position, further suggesting that these invasive tumors may become tethered to the chiasm and pull the optic apparatus into the sella. Alternative proposed etiologies for delayed visual loss following pituitary tumor resection include vascular compression, scarring and radiation effects [(Thome 2004) (Lee, 1983) (Adams 1988)].

### Risks of autologous grafting

Autologous grafting has long been part of closure techniques for skull base surgery, but it comes with some risks. These include an extra incision, with inherent risk of infection at donor or recipient sites, seroma formation, and donor site dehiscence. *Taha et al*. report on 10 complications in 974 cases in which autologous fat graft was used to reconstruct the skull base. They report this 1% rate of early and late complications secondary to fat necrosis, including sterile liquefied fat fistula, CSF leakage, and lipoid meningitis (Taha 2011). Sade adds that autologous graft can mimic tumor on imaging, making the identification of recurrence more difficult. This contrasts with surgical and fibrin glues, which produce a thin rim of hypointensity, which is distinctive from recurrence on MRI (Sade 2006). Additionally, packing the sella can cause complications secondary to mass effect, which would compromise the decompressive goal of macroadenoma resection (Slavin 1993).

## CONCLUSION

These data confirm that reconstruction of the sellar defect is not necessary to prevent optic chiasm prolapse following transsphenoidal resection of a pituitary macroadenoma. Furthermore, harvest of autologous tissues such as adipose tissue is not necessary for prevention of postoperative CSF leakage, even when an intraoperative CSF leak is experienced.

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# Management of Cerebrospinal Fluid Leaks of the Anterior and Lateral Skull Base

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**Key Words**

*Endoscopic Skull Base Surgery, Cerebrospinal Fluid Leak, CSF leak, Benign Intracranial Hypertension, Skull Base, Encephalocele, Endoscopic Sinus Surgery, Tegmen Tympani Defect*

## INTRODUCTION

Non-traumatic, spontaneous, or idiopathic cerebrospinal fluid leaks (CSF) along the anterior or lateral skull base are an increasingly recognized entity with improved endoscopic and imaging techniques.[1-8] In most cases of spontaneous CSF leaks, surgical intervention is generally warranted to resect the meningoencephalocele, repair the bony defect site and limit infectious sequelae.[9-10] While reconstruction of the skull base may be curative, patients with intracranial hypertension seem to be at increased risk of recurrent CSF leaks at the reconstruction site or elsewhere along the skull base.[2,5,7,8] Few studies compare anterior and lateral non-traumatic encephaloceles or present treatment algorithms to prevent against future CSF leaks. The goal of this study is to present our institutional experience and offer a treatment algorithm for patients presenting with anterior and lateral cranial base CSF leaks.

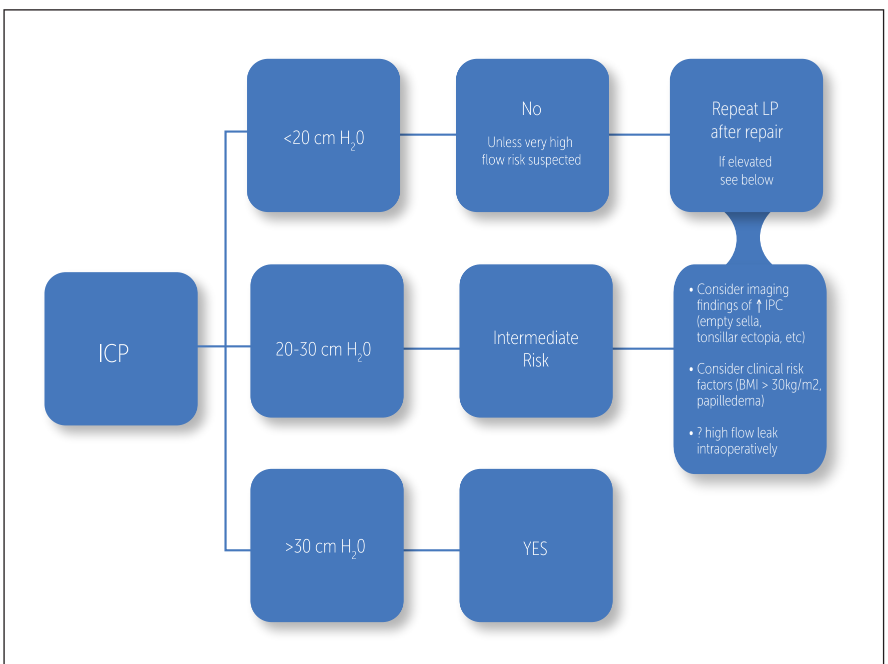


**Figure 1**

Clinical Management Algorithm for Long-term CSF Diversion with Ventriculoperitoneal Shunt in Non-traumatic CSF Leaks.

## METHODS AND RESULTS

### Patient Demographics

A total of 41 consecutive patients were identified and included in this review between March 2006 and January 2013. A summary of the preoperative demographics is shown in Table 1.

The average age of the patients was 58.34 $\pm$ 12.1 years with females disproportionately represented in the anterior cranial base (ACB) defect group (12 of 13 patient, 92.8%). The average BMI was 35.31 $\pm$ 8.1 kg/m$^2$ with 78% (32 of 41) of the patients being obese (BMI > 30 kg/m2). In 8 patients (19.5%), there was a prior history of meningitis.

Bilateral or multiple bony skull base defects were identified in 12 of the LCB patients (42.9%). An empty sella was noted on preoperative MRI in 4 LCB patients (14.2%) and four (30.8%) of the patients with ACB defects. Two (15.4%) patients in the ACB group had multiple or bilateral cranial base defects.

### Operative Details

The intraoperative findings are summarized in Table 2. All patients underwent a lumbar puncture under general anesthesia prior to skull base repair with recording of the opening CSF pressure (OP). The average preoperative OP for all patients was 23.09 ± 7.02 cm H2O. The average OP in the ACB group was 26.42 ± 7.93 cm H2O. The average OP in the LCB group was 21.19 ± 5.82 cm H2O.

### Intracranial Hypertension Management

Our experience with intracranial hypertension management is summarized in Table 3. Twenty-one patients in the study had a preoperative OP > 20 cm H2O. Ten of 13 (76.9%) ACB defect patients were found to have elevated OP compared to 11/28 (39.3%) of LCB patients. This was a statistically significant difference [p = 0.025].

Long-term CSF diversion in the form of ventriculoperitoneal shunting (VPS) was recommended to 14/21 (66.7%) patients with documented evidence of intracranial hypertension. Eleven of these 21 patients (52.4%) patients underwent VPS placement. Three of the 14 who were recommended VPS refused placement. In 6 others with an OP > 20 cm H2O, VP shunt placement was deferred based on no other high risk factors for recurrence.

### Patient Outcomes

During an average follow-up of 13.88 ± 15.4 months (range 1–84 months), three patients had recurrent or second-site CSF leaks (7.3%). All three patients refused a VP shunt at the initial repair despite our recommendations. Two patients developed a recurrence at the primary site of repair and a third developed a second site CSF leak 3 years later.

With regard to complications, no mortalities were observed with either primary surgical repair or VPS placement. One patient required ossicular chain reconstruction and another patient developed a local wound infection, meningitis, deep vein thrombosis, and postoperative seizures. These last 3 complications all occurred in 1 patient with a BMI of 40.4 kg/m2 and poorly controlled Type-2 diabetes mellitus. In terms of complications related to VPS placement, the overall incidence was 4 of 12 (33%). Two patients experienced distal shunt migration requiring reoperation. Two patients required reoperation for poor proximal ventricular catheter insertion secondary to slit ventricles.

## DISCUSSION

In this review, we gain insight into how anterior and lateral skull base CSF leaks compare. In terms of common clinical features, patients with recurrent CSF leaks in either location were more likely to have elevated OP at the time of initial repair. Of the 3 patients with recurrent or second-site CSF leaks in our cohort, all had OP ≥ 25 cm H2O (range 25-36). This suggests that elevated intracranial pressure is a highly relevant determinant of ultimate success regardless of site. In our cohort there was a statistically significant difference between anteriorly based defects versus laterally based defects in their likelihood of having elevated intracranial pressure (76.9% versus 39.3% [p = 0.025]) and patients with ACB CSF leaks were more likely to require long-term CSF diversion compared to LCB leaks (53.8% versus 17.9% [p = 0.018]).

There were interesting trends in clinical differences between the two groups as well. In our cohort, a relatively large percentage of our LCB patients were identified as having multiple ipsilateral or bilateral defects as compared to the ACB group (42.9% versus 15.4% [p = 0.082]). Additionally, when looking at all patients in our cohort, ACB defects were statistically more likely to be found in female patients compared to males (92.3% vs. 7.7% [p=0.001]).

At Thomas Jefferson University, our protocol for long-term management of CSF leaks incorporates CSF opening pressure measurements at the time of initial repair. For those patients with OP > 30 cm H2O, long-term CSF diversion with VPS placement is recommended. For those patients with OP < 20 cm H2O, long-term CSF diversion is not typically necessary for durable skull base repair, although high vigilance is maintained

**Table 1: Demographic characteristics of 41 patients with anterior and lateral CSF leaks.**

| Factor | No. (%) | | |
|---|---|---|---|
| | Total | Anterior | Lateral |
| Location of CSF leak | 41 | 13 (32) | 28 (68) |
| Mean age (years) | 58.3 | 59.9 | 57.6 |
| M:F | 13:28 | 1:12 | 12:16 |
| Mean BMI (kg/m$^2$) | 35.31 | 38.72 | 33.26 |
| History of meningitis | 7 (18.9) | 4 (30.8) | 4 (14.3) |
| Mean pre-op OP (cm $H_20$) | 23.09 | 26.42 | 21.19 |
| Bilateral or multiple defects | 14 (34.1) | 2 (15.4) | 12 (42.9) |
| Empty Sella | 8 (19.5) | 4 (30.8) | 4 (14.3) |
| Avg duration of follow-up (mo.) | 13.9 | 17.5 | 12.1 |

| Table 3. Characteristics and Management of 21 Patients with Elevated Intracranial Pressure (OP > 20 cm $H_2O$). | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Case No. | Location | | OP cm/$H_20$ | BMI | B/L or multiple defects | Empty Sella | VP Shunt Placed | Comment/VP Shunt Reasoning |
| | A | L | | | | | | |
| 1 | | + | 26 | 32 | Yes | - | - | Trauma suspected as cause |
| 2 | | + | 25 | 38.1 | - | - | - | Trauma suspected as cause |
| 3 | | + | 23 | 43.6 | - | - | Yes | High OP, Severe obesity (BMI >40) |
| 4 | | + | 25 | 34.1 | Yes | - | - | Patient refused VPS |
| 5 | | + | 25 | 37.8 | Yes | Yes | Yes | Multiple risk factors |
| 6 | | + | 31 | 29.2 | - | - | Yes | High-flow leak, OP>30 |
| 7 | | + | 33 | 49.9 | - | - | Yes | OP >30, severe obesity (BMI>40) |
| 8 | | + | 25 | 42.5 | Yes | - | - | Patient refused VPS |
| 9 | | + | 24 | 21 | - | - | - | Low BMI, no other risk factors |
| 10 | | + | 24 | 31.1 | - | - | - | No other risk factors, borderline BMI |
| 11 | + | | 27 | 32.8 | - | - | Yes | High-flow leak, high BMI |
| 12 | + | | 29 | 58.2 | - | Yes | Yes | Multiple risk factors |
| 13 | + | | 30 | 50.5 | - | Yes | Yes | Multiple risk factors |
| 14 | + | | 26 | 37.9 | - | - | Yes | High OP, High BMI |
| 15 | + | | 29 | 30.6 | - | - | - | Possible trauma as cause, borderline BMI |
| 16 | + | | 33 | 51.7 | - | Yes | - | Refused VP initially (VPS after recurrence 1 month post-op) |
| 17 | | + | 24 | 37.9 | - | - | - | High BMI, but no other factors |
| 18 | + | | 31 | 40.8 | - | - | Yes | Multiple risk factors, OP>30 |
| 19 | + | | 27 | 31.2 | - | - | - | Borderline BMI, but no other factors |
| 20 | + | | 27 | 38.8 | Yes | Yes | Yes | Multiple risk factors |
| 21 | + | | 36 | 41.8 | Yes | - | Yes | Multiple risk factors, OP >30 |
| **TOTAL** | **10** | **11** | **27.6 avg** | **38.6 avg** | **6** | **5** | **11** | **14 (66.7%) patients were recommended VPS** |

if there are other additional clinical risk factors for intracranial hypertension such as BMI > 35 kg/m2, evidence of empty sella on radiographic imaging, or a history of previous CSF leak repairs . When these risk factors are present, we frequently perform a delayed repeat LP following repair to determine whether the OP has increased. The most difficult to manage group are those patients with intermediately elevated OP between 20-30 cm H2O. Typically, if patients have multiple clinical signs that suggest intracranial hypertension then we will offer long term CSF diversion with VPS. In our review, 6 of 15 (40%) patients in the intermediately elevated OP group ultimately underwent VPS placement based on high-risk clinical features without a subsequent CSF leak.

## CONCLUSION

Successful repair of CSF leaks from the anterior and lateral cranial base is achieved with meticulous surgical technique. In patients with OP > 30 cm H20 or <20 cm H20 the decision to recommend a VP shunt is often uncomplicated. However, in those patients with intermediately elevated OP (20-30 cm H2O), a high index of clinical suspicion is warranted and identification of high-risk clinical features is critical to avoid under treatment of intracranial hypertension and to prevent avoidable recurrences of CSF fistula or infectious sequelae.

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# Prevention and Management of Bleeding During Endoscopic Approaches to Skull Base Pathologies

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**Keywords**

*Anatomy, complications, endoscopic, management*

**Conflicts of interest**

none

## BACKGROUND

The rate of serious permanent morbidity and mortality with endonasal approaches has declined secondary to increased knowledge of the pertinent anatomy, advanced neuroimaging and navigation techniques, better surgical instruments, and improved exposure and reconstruction strategies.[1-3] Although rare, vascular injury remains a potentially serious complication. However, with limited systematically-collected and reported data, the exact incidence rate of vascular injuries is difficult to determine. In terms of arterial injuries, the incidence based on reported series likely ranges from 0.3%-9% (Table 1),[4-11] with higher rates most commonly associated with chordomas and chondrosarcomas involving the clivus. Venous injury is comparatively less severe and easier to manage. As a result, there is a comparatively lower impetus to publish epidemiological data and management strategies for these injuries. The consequences of arterial injury include fatal hemorrhage, vessel occlusion or thromboembolism causing infarction, development of a pseudoaneurysm (PA), carotid-cavernous fistula (CCF), subarachnoid hemorrhage (SAH), and vasospasm.[6,7,9] Surgical expertise and detailed knowledge of the neurovascular anatomy is critical to the avoidance and management of vascular injuries.

### Avoidance of vascular Injury

*Pertinent vascular anatomy*

The dominant venous structures in skull base surgery are the cavernous sinuses (CS) flanking the sellar region and the basilar venous plexus on the dorsal surface of the clivus.[12] The CS on either side are connected through the superior and inferior inter-cavernous sinuses; these need to be identified during drilling of the sellar bone and managed during opening of the dura. The internal carotid arteries (ICAs) coursing within the CS are the most vulnerable major arteries in the approach toward the sellar/parasellar regions. The distance between the cavernous carotids is on average 23mm (Range 12-30mm),[13-15] though rarely this may be as small as 4mm.[16] The parasellar ICA may potentially be devoid of sphenoid bone coverage in up to 4% of the population.[16] This defect may not be readily identified on preoperative imaging and its potential presence must be kept in mind during drilling of the sellar bone or using monopolar cautery in this area. In approximately 25% of the population the ICAs penetrate the medial wall of the cavernous sinus and directly contact the gland, potentially hindering the ability to develop a surgical plane during tumor dissection.[17] Sellar neoplasms may displace the cavernous carotids laterally or encase the vessels altogether, increasing the risk of intraoperative hemorrhage from the ICA or its branches.

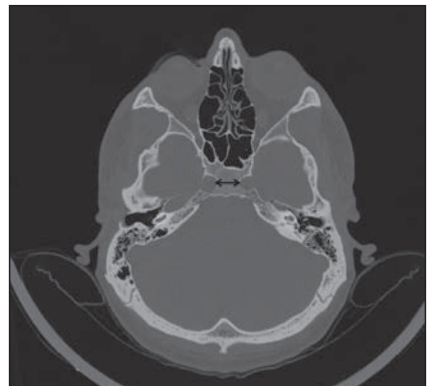


**Figure 1A**

Axial CT scan depicting a narrowed inter-carotid artery distance.

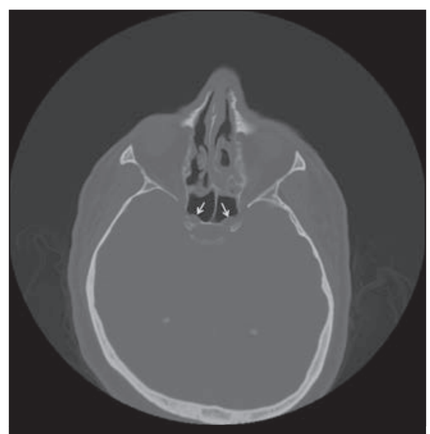


**Figure 1B**

Axial CT scan depicting bony dehiscence (arrows) overlying the carotid prominences within the sphenoid sinus.

## Adjuncts for management of hemorrhage

*Preoperative*

Imaging can help elucidate the relationship between critical neurovascular structures and the pathology. Balloon test occlusion (BTO) with neuro-monitoring may be indicated in cases wherein the potential for vascular injury is high (e.g. extensive vascular encasement by the pathology). Embolization of potentially vascular tumors may be necessary to minimize intraoperative bleeding.

### Intraoperative

Neuro-monitoring can be critical during the management of intraoperative vascular complications, through either indicating the neurological impact of active hemorrhage or the consequences of over-packing the site of hemorrhage during hemostasis. For example, over-packing of ICA bleeding can result in the compression of cranial nerves and even loss of anterograde blood flow, both of which can be detected with intraoperative neuro-monitoring.

Using computerized surgical navigation and micro-doppler ultrasonography, location of the ICA can be confirmed prior to surgical drilling or incising the dura. In addition, the evolution of surgical tool design has contributed to minimizing the risk of vascular injury during dural opening as well; examples of these include the low-profile angled blades or scissors which direct cutting force away from the intradural surface.[7,17] Intradurally, sharp extra-capsular dissection of arachnoid planes and central debulking of tumors (to avoid vessel avulsion) are important strategies. If efforts in developing a plane between the tumor and a surrounding neurovascular structure are not successful, a subtotal resection may be advisable.

### Management of intraoperative bleeding

General: Regardless of the degree of bleeding, it is essential that the endoscope is not withdrawn from the surgical site. A pitfall is to over-pack the repair, which may result in carotid occlusion; neuro-monitoring should be assessed during such maneuvers to prevent irreversible ischemia.

### Venous

A nuisance, but rarely life threatening. Total intravenous anesthesia does not increase intracranial pressure, which is helpful for minimizing venous bleeding. Although CS bleeding can be brisk, it is usually easily managed with head elevation and gentle packing with Surgicel or FloSeal.

**Arterial:** The majority of ICA injuries are small and can be immediately controlled with rudimentary hemostatic methods (e.g. Gelfoam and the application of pressure with a cottonoid patty). Small lacerations can sometimes be definitively repaired with bipolar coagulation and packing with Surgicel. Larger ICA injuries during endonasal surgery are much more difficult to manage. A number of packing materials and techniques have been described, including gelfoam, fibrin glue, muslin gauze, and a crushed muscle patch.[18-20] Larger lacerations can be managed with a myriad of strategies such as utilizing a two-layered muslin gauze patch that is reinforced with a fat graft or collagen sponge.[21,7] Direct repair or reinforcement of the laceration may not be feasible and vessel sacrifice may be necessary. An immediate postoperative angiogram is critical to evaluate the vessel repair and to rule out early postoperative pseudoaneurysm formation.

Pseudoaneurysms (PAs): The rate of postoperative ICA PA formation is highest with direct vessel injury.[22] PA rupture, typically within days to weeks from diagnosis, may result in SAH, CCF, life-threatening epistaxis, or a nidus for distal thromboembolism/infarction.[23,24] Even with a normal immediate postoperative angiogram, a repeat angiogram should be repeated within 7-10 days, particularly when suspicion for ICA injury is high. If open craniotomy to sacrifice the vessel is undertaken, an angiogram is necessary for assessing collateral circulation and the feasibility of an extracranial-intracranial bypass.[21] Endovascular management is an alternative and includes complete ICA occlusion, coiling the PA, or vessel reconstruction with stent-assisted coiling. Coiling alone is often not successful and there is a possibility for dissection or thromboembolic events.[25] Endovascular stenting may be a more feasible option.[26]

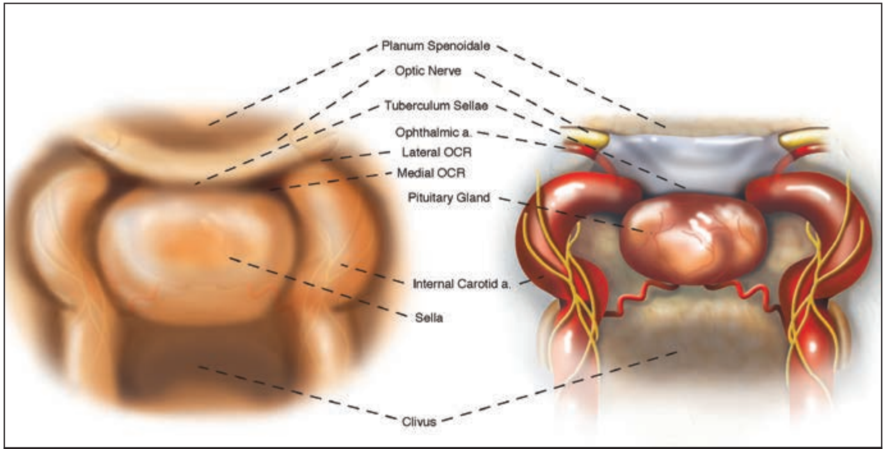



**Figure 2**

Although perforating branches of the ICA are small and injury to them can easily be controlled, their supply of critical structures makes the neurological consequence of sacrificing these vessels potentially dire.

## CASE REPORT

A 51-year-old male presented with a three-month history of progressive visual loss. Formal visual field testing and optical coherence tomography (OCT) revealed a chiasmal compression pattern. Contrast MRI showed a large meningioma growing along the planum sphenoidale, sella, and eroding into the sphenoid sinus (Figure 3A-D). An endoscopic endonasal approach for tumor resection was performed. Intraoperatively, a small amount of arterial bleeding was observed while aspirating tumor in the vicinity of the left ICA. The bleeding was controlled with FloSeal and the application of pressure with a cottonoid. As adequate tumor debulking had already been achieved, the procedure was stopped as a precaution due to the concern of possible ICA injury.

Immediate postoperative examination showed improved visual field exam and no other changes neurologically. MRI showed significant tumor debulking and decompression of the optic chiasm. Early in the post-operative course MRA, CTA, and an angiogram revealed normal intracranial vasculature.

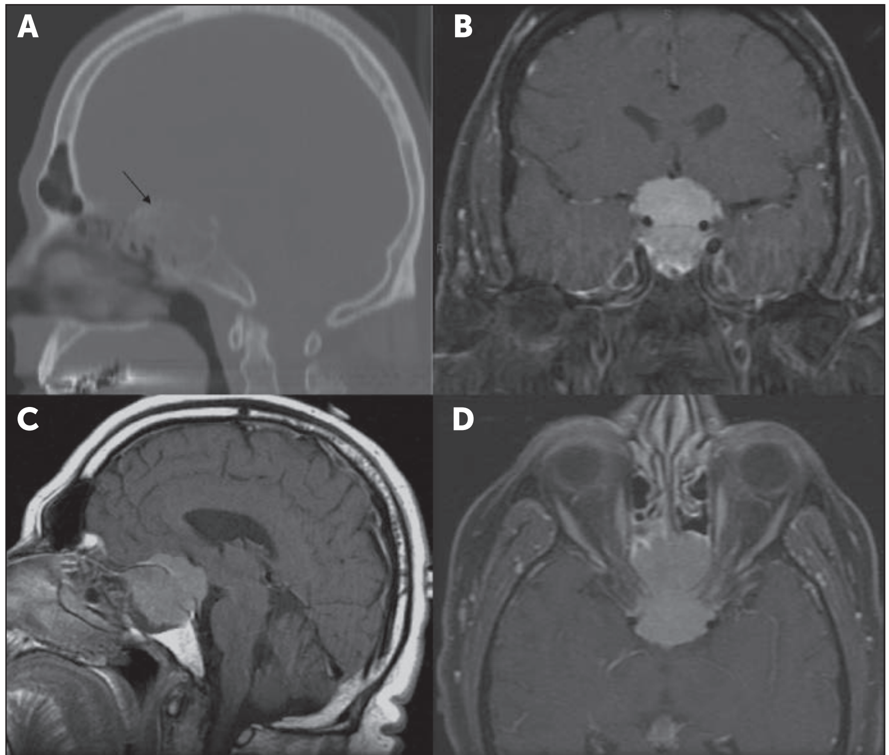



**Figure 3**

Preoperative imaging. A) Sagittal CT scan demonstrating extensive calcification of tumor (arrow). B) Coronal T1+contrast MRI demonstrating suprasellar extension of lesion and extension of tumor beyond the lateral margin of the cavernous carotid arteries. C) Sagittal and D) Axial T1+contrast MRI demonstrating invasion of the sphenoid sinus.

> **Learning point #1:**
>
> **In cavernous sinus meningiomas, there is usually no adequate plane between the ICA and the tumor.**

Two weeks postoperatively the patient was readmitted with the acute onset of severe epistaxis, which was temporarily controlled with nasal packing. Emergent angiogram revealed a left cavernous ICA PA (Figure 4A-B). Balloon test occlusion showed no venous filling delay and the patient passed a hypotensive challenge. Several options were considered, including ICA sacrifice, bypass, and coiling of the PA. Ultimately, the PA was coiled. Although the epistaxis completely resolved, dissection and stenosis of the left ICA resulted in intermittent hemiparesis and impaired language. Imaging-confirmed left ICA dissection and embolic phenomena (Figure 5A). The decision was thus made to occlude the parent vessel with coils delivered through an endovascular approach (Figure 5B). One week after left ICA occlusion, the patient developed symptoms of left hemisphere hypoperfusion that became refractory to medical intervention with fluids and vasopressors. CTA confirmed the suspicion of diminished collateral vascular supply (Figure 6A). Thus, the decision was made to perform an external-to-internal carotid artery bypass (Figure 6B).

> **Learning point #2:**
>
> **If a carotid injury is suspected, close post-operative assessment is necessary:**
>
> **Keep Looking!**

On immediate postoperative exam, the patient exhibited no residual weakness. The residual meningioma was subsequently treated with fractionated stereotactic radiotherapy and the patient remains stable for over five years since initial surgery.

## CONCLUDING KEY POINTS

1. Endonasal anatomical and technical expertise is necessary to avoid and manage vascular injuries
2. Cavernous sinus meningiomas may not have a plane separating them from the ICA
3. If ICA injury suspected, keep looking!
4. ICA pseudo-aneurysms are best treated by vessel occlusion and early bypass when indicated

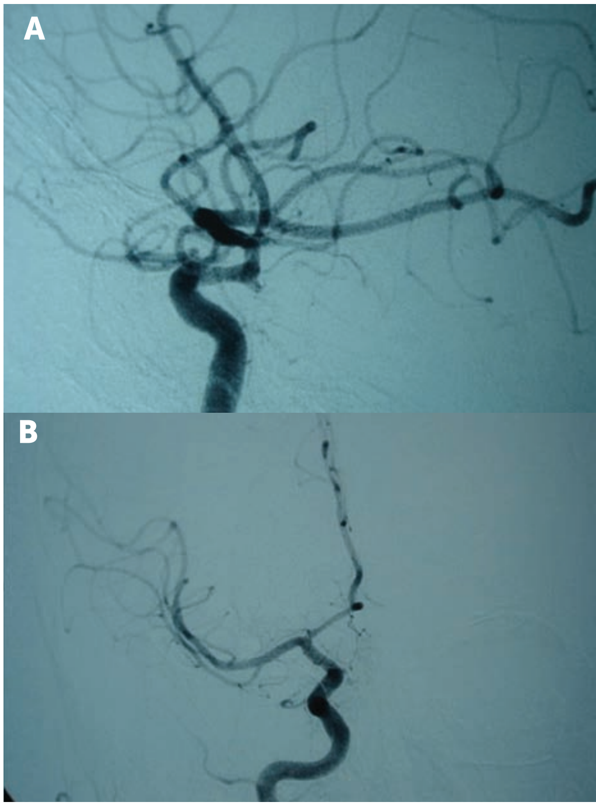
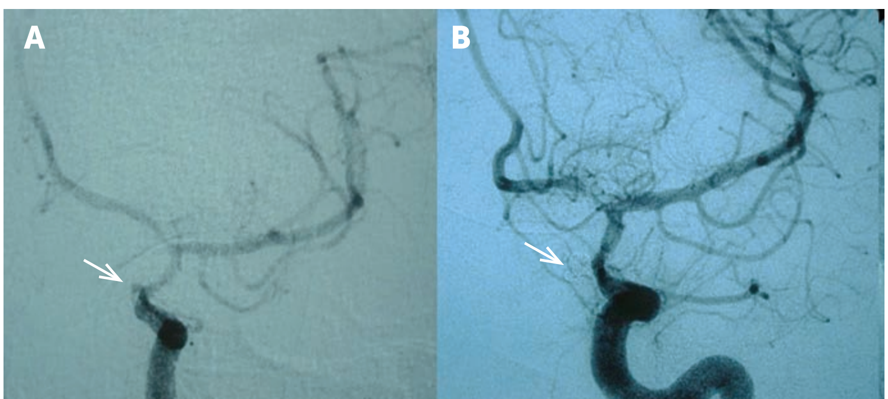


**Figure 4**

Immediate postoperative angiogram of carotid arteries showing normal appearance of vessels; A) Left internal carotid artery and B) Right carotid artery



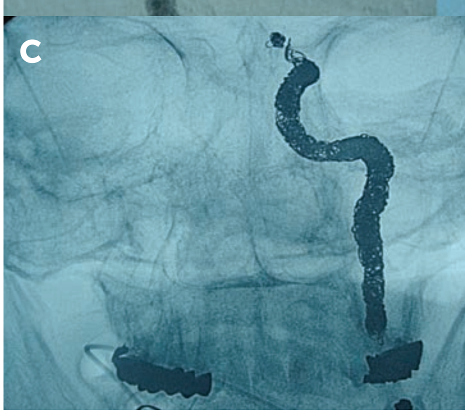


**Figure 5**

Angiogram of left internal carotid artery. **A.** Prior to coiling of pseudoaneurysm (white arrow) and **B.** following coiling. **C.** The vessel was eventually sacrificed through endovascular approach due to intermittent embolic events.

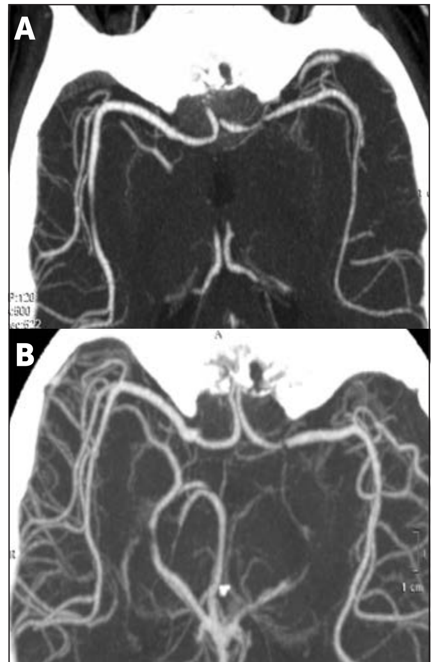


**Figure 6**

Axial CTA of vascular supply to cerebral hemispheres in **A.** preoperative and **B.** postoperative settings.

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# Endoscopic Repair of High-Flow Cerebrospinal Fluid Leaks Using a Bilayered Fascia Lata "Button" Graft

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## INTRODUCTION

Closure of dural defects in extended endoscopic transnasal approaches remains a challenge with published cerebrospinal fluid (CSF) leak rates higher than those reported with transcranial approaches. The use of a vascularized nasoseptal flap (NSF) has significantly reduced the rate of postoperative CSF leak experienced with endoscopic approaches, however, the NSF primarily serves as a bolster or reinforcement of the primary dural closure. In 2010, we described our initial experience with a novel endoscopic dural repair technique developed at TJUH using a bilayer "button" of fascia lata to repair high-flow CSF leaks.[1] In this study, we describe our subsequent experience using this endoscopic closure technique for repair of high-flow CSF leaks.

## METHODS

Data was obtained from our prospective endoscopic skull base database with review of cases between 2010-2014. Patients with high-flow CSF leaks involving direct opening into a cistern or ventricle were included and closure technique was determined. Sixty-six cases of high-flow CSF leaks with repair using "button" graft technique were identified. The "button" repair consists of a bilayer fascia lata graft that is constructed with an inlay component that is placed in the subdural space and an onlay component covering the epidural space to create a watertight primary dural repair (Figure 1). The fascia lata is harvested at the time of dural closure from the lateral thigh using non-contaminated instruments. The inlay portion is then fashioned to be approximately 25-30% larger than the dural defect and the onlay portion approximately 5-10% larger than the defect (Figure 2). The two pieces are then sutured together with two to four 4-0 Neurolon sutures (Ethicon, Bridgewater, NJ) within the central aspect of the graft. The "button" is then maneuvered to cover the dural defect first securing the inlay component before placement of the onlay component. A watertight seal is confirmed with Valsalva maneuver and the repair may then be reinforced with the NSF as necessary.

## RESULTS

Among the 66 cases with "button" graft repair, the most common indications were for repair of defects associated with meningioma and craniopharyngioma resection (29% and 27%, respectively; Figure 3). Other common pathologies included pituitary macroadenoma (15%), esthesioneuroblastoma (6%), and Rathke's cleft cyst (6%). The most common anatomic site of reconstruction was the planum sphenoidale (Figure 4) The population characteristics included an average age of 54 years and an average Body Mass Index of 30. In 59/66 cases, the primary "button" repair was accompanied by NSF placement. Overall, 2/66 (3%) patients experienced postoperative CSF leaks (Figure 5). Of the 7 cases in which no NSF was placed, no postoperative CSF leaks were encountered. Lumbar drains were placed at surgery in 9/66 (13.6%) cases with a six day average hospital length of stay. No complications related to fascia lata harvest or "button" graft placement were encountered.

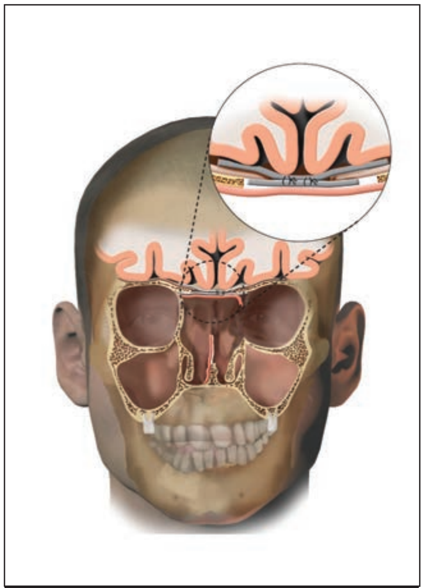

**Figure 1**

Primary bilayer "button" graft closure of the anterior cranial base with nasoseptal flap reinforcement.

## DISCUSSION

Initial experience with expanded endoscopic cranial base approaches was complicated by extremely high rates of postoperative CSF leakage. The pedicled Hadad-Bassagasteguy NSF significantly reduced these rates toward those experienced with transcranial rates, however, in our experience a primary watertight dural closure remains critical to successful cranial base reconstruction.[2] Several different primary repair techniques have been described including our "button" graft. In this study, we demonstrate that this closure technique is highly effective in repairing large skull base defects associated with high-flow CSF leaks with only a 3% rate of postoperative CSF leak observed in a large number of patients.

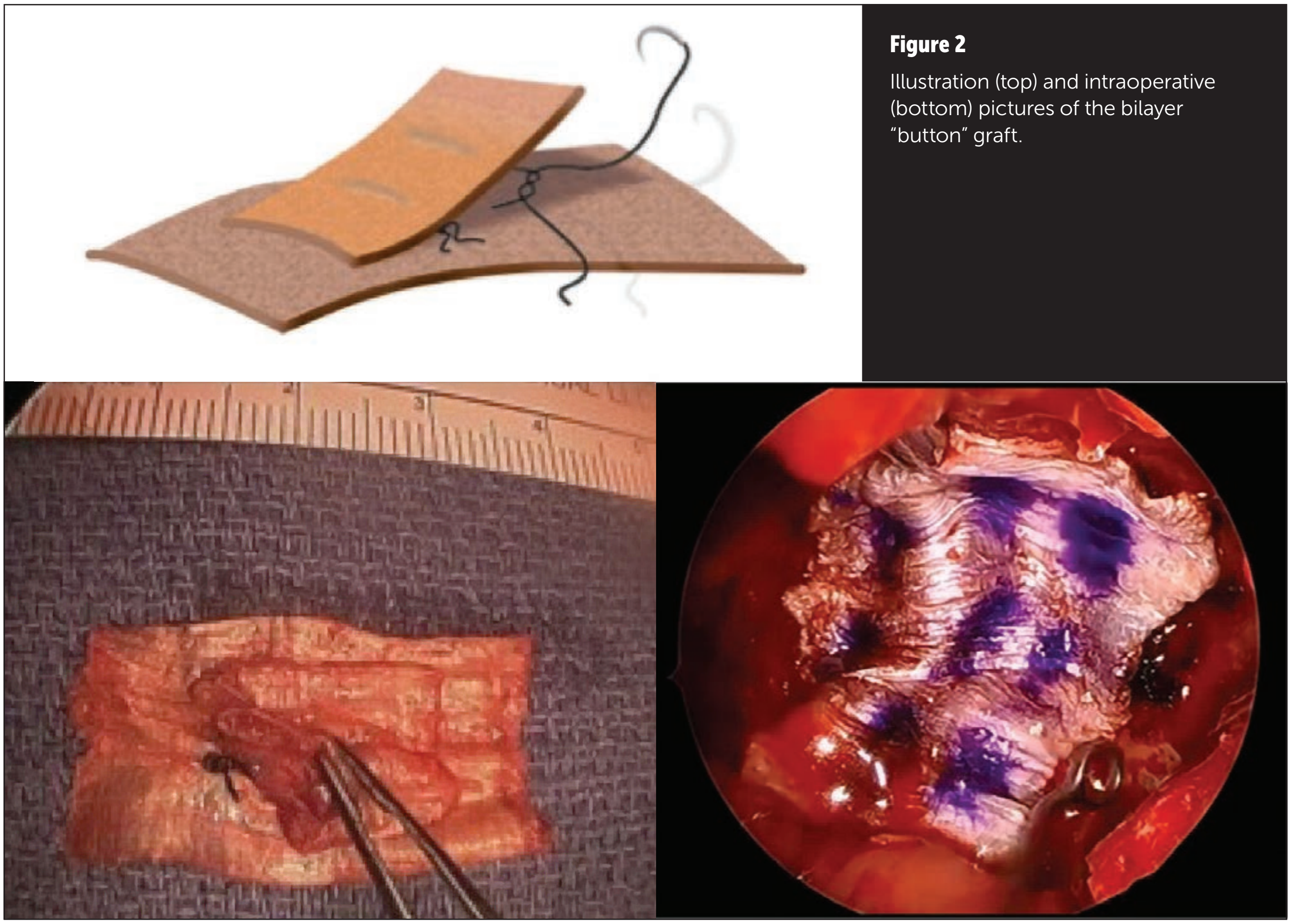

**Figure 2**

Illustration (top) and intraoperative (bottom) pictures of the bilayer “button” graft.

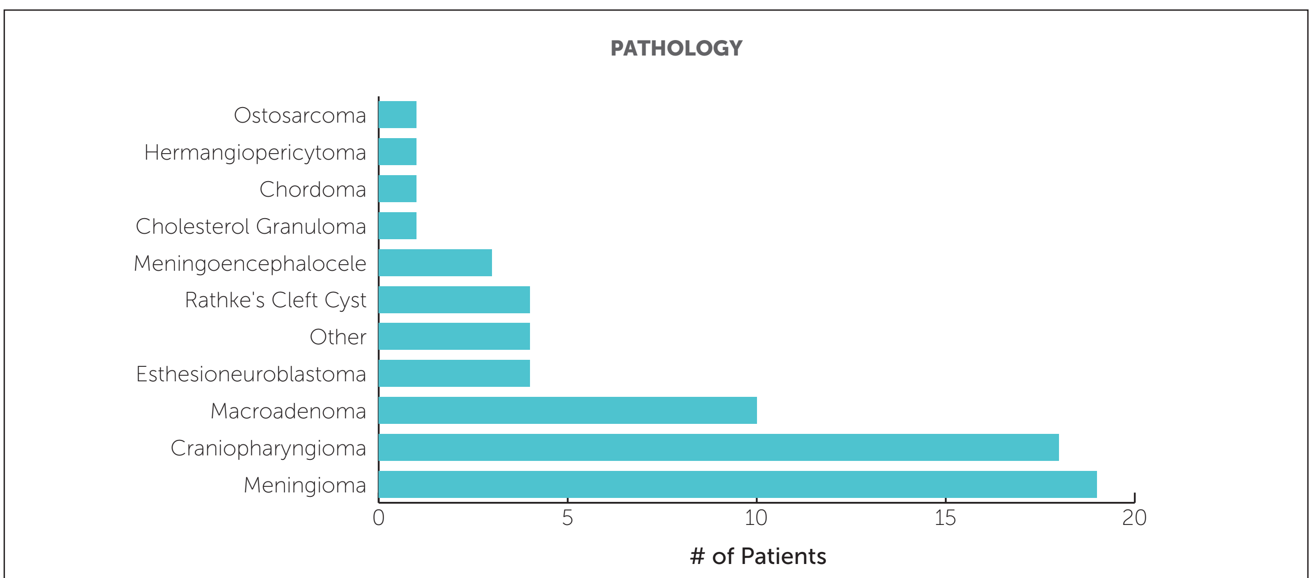


**Figure 3**

Pathologic indications for bilayer “button” graft placement.

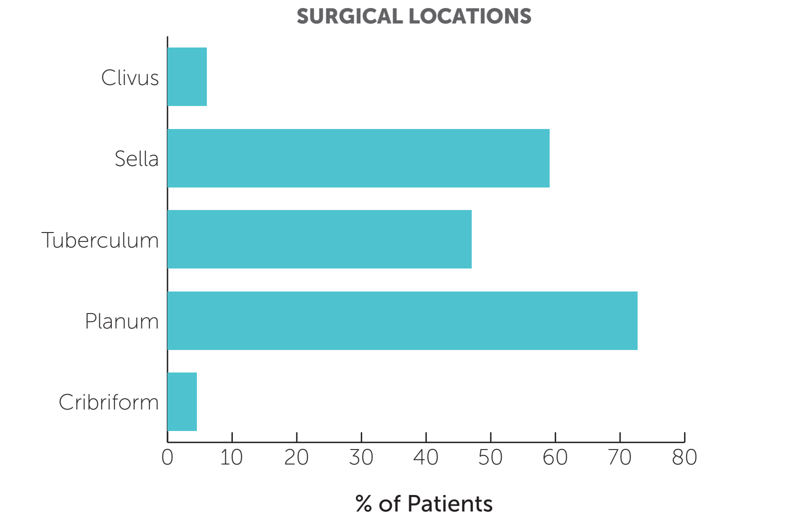


**Figure 4**

Figure 4: Skull base anatomic locations of bilayer "button" graft placement.

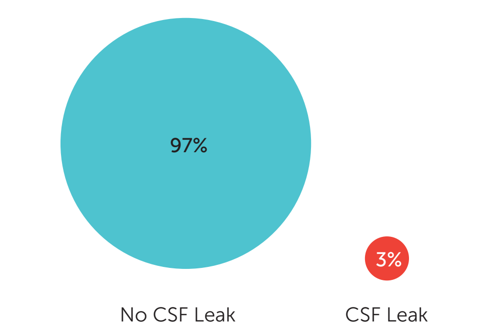


**Figure 5**

Postoperative CSF leak rates with bilayer "button" graft placement.

Although the "button" graft requires harvest of fascia lata, no complications related to harvest were encountered. Additionally, as opposed to rigid buttress repairs, the pliable fascia lata "button" can be safely placed in the regions of the optic nerves without concern for injury making this repair technique extremely versatile.

## CONCLUSION

The bilayer "button" graft is an effective, safe, and versatile primary dural repair technique for extended endoscopic cranial base approaches, especially when supplement by nasoseptal flap placement.

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# Endonasal Vascularized Flaps For Cranial Base Reconstruction

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## INTRODUCTION

Since the introduction of extended endoscopic cranial base surgery, postoperative cerebrospinal fluid (CSF) leak has been a formidable and troublesome issue resulting in complications such meningitis, pneumocephalus, and the need for additional surgical interventions. Establishment of a watertight cranial base reconstruction is the most critical step in preventing postoperative CSF leakage. Historically, various free grafts, both synthetic and autologous, were utilized as repair materials for reconstruction of the cranial base defect often in combination with temporary CSF diversion. Free grafts are often sufficient for repair of small low flow, low pressure dural defects. High postoperative CSF leak rates reported in the initial endoscopic skull base literature are evidence that free grafts do not provide a reliably competent repair for large defects or direct high-flow CSF leaks. The introduction of the Hadad-Bassagasteguy vascularized nasoseptal flap has significantly reduced the reported CSF leak rate with a recent meta-analysis reporting that use of the vascularized flap is associated with a 7% rate of postoperative CSF leakage compared to 16% with free grafts alone for large dural defects.[6] Since the initial description of the vascularized pedicled nasoseptal flap in 2006, many surgeons have developed a variety of alternative vascularized flaps for endonasal cranial base reconstruction. In this article, we summarize and compare several of the most clinically useful vascularized flaps including their harvest technique, indications and limitations, and potential complications.

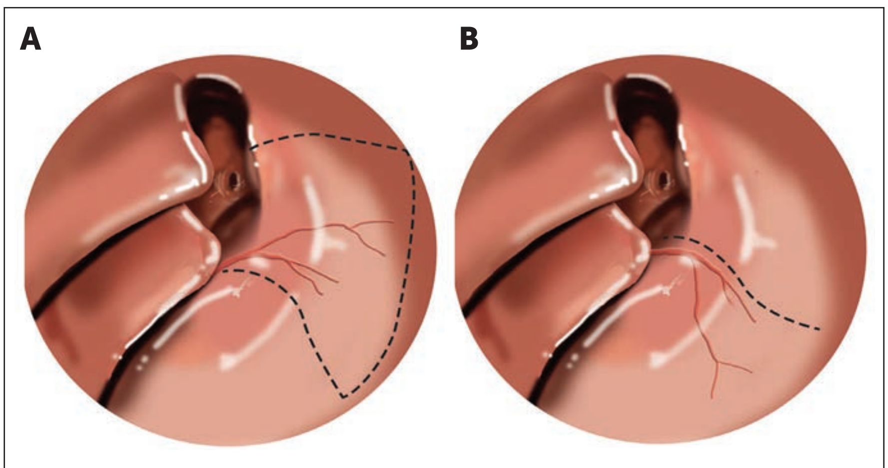


**Figure 1**

(A) Incisions (dotted lines) for standard Nasoseptal Flap and (B) Rescue Flap.

## I. PEDICLED NASOSEPTAL FLAP

The pedicled nasoseptal flap (NSF) as described by Hadad and colleagues is a mucoperiosteal and mucoperichondrial flap of the nasal septum based on the nasoseptal artery, a branch of the sphenophalatine artery.[5] The nasoseptal flap is extremely versatile and allows for an extensive area of coverage with cadaveric studies demonstrating a mean NSF surface area of 17cm.[2,9] The harvested NSF varies between 5-8cm in length and 5cm in width, enabling reconstruction from the posterior wall of the frontal sinus to the clivus in the sagittal plane and from orbit to orbit.[3-4] The flap's rich and long vascular pedicle with multiple branches and anastomoses provides consistent vascularity, allowing it to be harvested early in the course of surgery and stored in the nasopharynx as well as re-mobilized should future surgeries be necessary. The major drawback of the NSF is that it must be harvested during the initial stages of endonasal surgery before any disruption of the vascular supply has occurred. Additionally, harvest of the NSF creates a large anterior mucosal defect at the donor site, resulting in significant postoperative nasal crusting and need for multiple debridements. Although postoperative olfactory dysfunction is typically transient, higher rates of permanent olfactory loss have been reported in patients undergoing extended approaches with NSF elevation.[12,14] Nasal septal perforation may also rarely occur.[15]

An understanding of the vascular supply to the nasal septum is critical for successful harvest of a robust NSF. The sphenopalatine artery is a terminal branch of the internal maxillary artery. It exits the pterygopalatine fossa and enters the nasal cavity through the sphenopalatine foramen before dividing into the posterior lateral nasal artery and nasoseptal artery. The NSF is developed by creating two parallel incisions in the

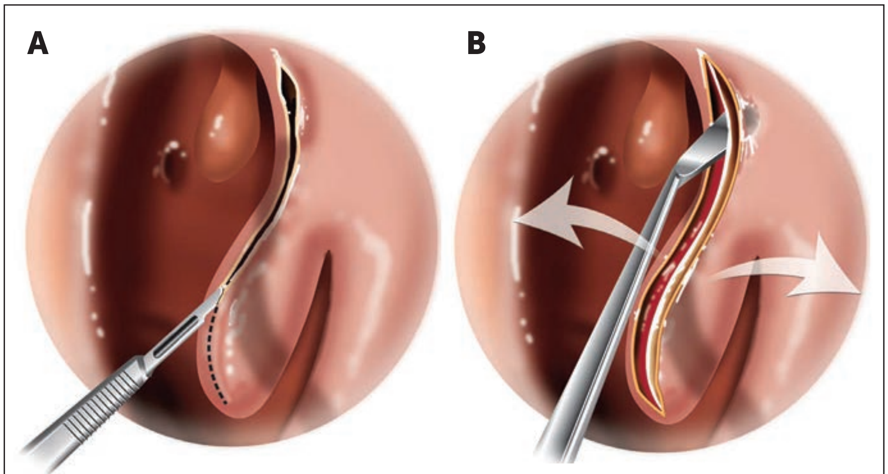


**Figure 2**

(A) Incision for Middle Turbinate Flap. (B) The flap is then spread like an "open book".

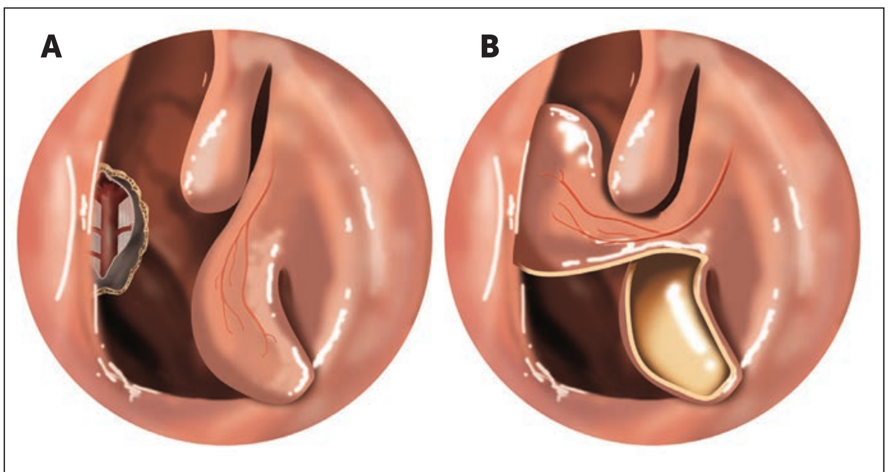


**Figure 3**

(A) Incision for harvest of the Inferior Turbinate Flap which is suitable for covering small clival defects (*). (B) After removal of the inferior turbinate, the flap is rotated to provide coverage.

sagittal plane along the septum with an anterior vertical connecting incision. Electrocautery or cold steel may be used for harvest with electrocautery having the advantage of minimizing bothersome oozing throughout the surgery but slightly diminishing the end-size of the flap. The superior incision begins at the superior aspect of the sphenoid os and is carried anteriorly and superiorly at the level of the superior turbinate. A 1 to 2 cm strip of the superior septum is preserved to minimize an olfactory deficit. The anterior extent, or size of the flap depends on the coverage area anticipated. Lack of preservation of the superior strip may result in anosmia. The inferior incision is made along the floor of the nasal cavity and may be extended laterally until under the inferior turbinate if wider coverage is necessary, although this increases the risk of superior alveolar nerve injury (Figure 1). One of the main limitations of the NSF is that it must be harvested early during the course of surgery before its blood supply is disrupted. Although the NSF can be harvested routinely and returned to its normal position should a vascularized flap not prove necessary, this routine practice is time consuming and carries all of the potential risks of NSF harvest including nasal crusting, septal perforation, prolonged healing, and anosmia. For certain endonasal procedures such as pituitary surgery, reconstruction with the NSF is rarely necessary. Elsewhere in this journal we describe the TJUH approaches to the skull base that preserve the vascular supply to the NSF including the "1.5" and submucosal "tunnel" approaches. Other groups have developed similar modifications designed to allow for delayed NSF harvest. Rivera-Serrano et al. and Griffiths et al. have described their "rescue flap" modifications which preserve the NSF blood supply while enabling a bilateral sphenoidotomy and limited posterior septectomy to be performed for access to the sella.[4,11] In these modifications, the superior incision of the NSF is performed and the in underlying mucosa inferiorly is elevated with preservation of the vascular pedicle and the superior olfactory strip (SOS). Mucoperiosteal incisions are made starting just inferior to the sphenoid ostium and extending laterally for a few millimeters. The incision is carried anteriorly and horizontally for approximately 2cm along the perpendicular plate of the ethmoid and posterior nasal septum, and ending at a point opposite to the anterior border of the middle turbinate. It is then extended further anteriorly and superiorly in a hockey-shaped fashion to facilitate flap mobilization (Figure 1).

## II. TURBINATE FLAPS

Although the NSF serves as the workhorse of endonasal cranial base reconstruction, its utility is limited for repair of more anteriorly located defects in the region of the frontal sinus and harvest of a vascularized NSF may not always be possible in the setting of prior surgery or malignancy where the septal mucosa may be compromised. As such, a variety of turbinate flaps have been described which are based on the blood supply to the lateral nasal wall. These turbinate flaps may be performed unilaterally or bilaterally as necessary to provide coverage.

### A. Middle Turbinate Flap

The vascularized middle turbinate flap was first proposed in a 2009 cadaveric study. Since that time, a variety of clinical applications have been reported.[10,13] The posterior lateral nasal artery, a branch of sphenopalatine artery, serves as the vascular pedicle for the middle turbinate flap and the flap best suited for coverage of small- to moderate-sized dural defects in the sellar, planum sphenoidale and fovea ethomoidalis areas. Coverage of the olfactory groove and mid- to lower-clival regions is not possible with the middle turbinate flap. The reported a mean surface area for the flap of 5.6cm[2] with the length ranging from approximately 3-4cm and width of 1-2cm.[3] Coverage of sellar defects requires that a flap 4cm length should be secured and preoperative measurement of the middle turbinate length using imaging can be used to predict the available flap length.

The flap is harvested by creating a vertical incision along the anterior face of the middle turbinate. Subperiosteal elevation of the mucoperiosteum is carried out bilaterally along the medial and lateral slopes of the turbinate. Once the mucoperiosteum has been raised, the bony turbinate is removed and a cut is made through the middle turbinate's axilla. The incision is extended dorso-caudally along the sagittal plane until the mucosa is completely divided and unfolded in an open book fashion, taking great care to not disrupt the blood supply to the flap. It is critical that the incisions at the medial and lateral aspect of the turbinate remain below the level of the ethmoids and cribriform plate to avoid iatrogenic CSF leakage (Figure 2). Aberrant pneumatization of the turbinate may also lead to inadvertent leakage. Similar to the NSF, some postoperative crusting is to be expected.[13]

### B. Inferior Turbinate Flap

In 2007, Fortes et al. reported a posterior pedicle inferior turbinate flap (PPITF). For this flap, the vascular pedicle is supplied from the inferior turbinate artery, a terminal branch of the posterior lateral nasal artery.[2] The inferior turbinate artery enters the inferior turbinate posteriorly along its lateral surface.[8] Inferior turbinate flap is indicated for smaller defects of the sella, posterior fossa and clivus. The reported size of the flap varies widely in the literature with the length of the flap ranging from 2-5cm (Table 1). Unless the flap is extended along the lateral nasal wall, the flap is narrow in width ranging from 1.2-1.4cm.[3] Because of its origin near the nasal cavity floor and limited arc of rotation, the inferior turbinate flap is not recommended for anterior skull base coverage. Crusting occurs over the exposed inferior turbinate bone and requires frequent debridement.

The flap is harvested by creating two parallel incisions along the superior and inferior aspects of the turbinate and connected with an anterior vertical incision along the head of the turbinate. Importantly, the vascular pedicle is located along the superior aspect of the inferior turbinate's lateral attachment. Additionally, it is important to preserve the lateral nasal artery as it descends vertically over the ascending process of the palatine bone and care must be taken not to injure nasolacrimal duct during the harvest (Figure 3).

### C. Superior Turbinate Flap

Superior turbinate osteoplastic (STOP) flap is novel method developed by Thomas Jefferson University Hospital Cranial Base Team (see additional article in this edition for further details). This is a suitable alternative for anterior skull base coverage when the NSF is unavailable or compromised. The superior turbinate has multiple arterial feeders from the nasoseptal artery, posterior lateral nasal artery, and posterior ethmoidal artery. Its proximity to the anterior skull base and ample blood supply make the superior turbinate a convenient source for vascularized reconstruction. The STOP flap utilizes both the superior turbinate bone and mucosa with the composite nature providing additional support and rigidity. The main limitation of the STOP flap is the limited size of the superior turbinate and its variability among individuals. Additionally, the limited arc of rotation of the STOP flap restricts its use to the anterior skull base.

To harvest the STOP flap, the lateral half of the superior turbinate mucosa is carefully removed with preservation of the underlying bone. The vascularized osteoplastic flap is then reflected. Care must be taken not to cover local mucosa by the STOP flap to avoid the risk of mucocele. Other complications are extremely rare and bilateral superior turbinate flaps may be utilized as necessary.

## III. TEMPOROPARIETAL FASCIA FLAP

The temporoparietal flap (TPF), though used in a wide variety of reconstructive settings, was first described in 2007 for endoscopic endonasal reconstruction.[16] Extensively described in the literature, it is the third layer located in the scalp below the skin and subcutaneous tissue.[17] The flap is commonly supplied by anterior frontal branch of the superficial temporal artery (STA) with one or two veins accompanying the STA for drainage.[3] TPF has a thickness of 2 to 3 mm.[18] The flap can be extended above the temporal line to include the gala, allowing the flap to as large as 14 x 17 cm.[19] The temporoparietal flap requires an external incision making for a durable reconstruction when previous surgery or treatment precludes the use of intranasal pedicled flaps. This technically challenging flap has a low risk of alopecia and frontal nerve injury in experienced hands.

After the defect has been identified, a maxillary antrostomy and total ethmoidectomy are performed on the side which the flap will be raised. Next, the pterygopalatine fossa is completely opened as the entire posterior maxillary wall is removed. Particular attention is paid to the superior lateral aspect of the posterior maxillary wall. A hemicoronal incision is made in the scalp. The skin and subcutaneous tissue are dissected free exposing the lateral surface of the TPF. Meticulous and slow dissection must be undertaken here as the scalp has a rich vasculature and the pedicle vessels can easily be injured. In cases where a wide flap is needed, the frontal branch is identified as it courses though the frontalis muscle. Once adequate exposure is obtained, the flap is outlined and incised as the TPF is elevated off of the periosteum and temporalis muscle. The temporalis muscle has an origin on the lateral orbital rim, which must be released to communicate with the infratemporal fossa. Next a dilator is inserted to enlarge this communication producing a tunnel large enough to pull the flap though. The orientation of the pedicle is monitored to ensure it is not kinked or compressed. The pedicle can also be lengthened to extend the coverage intranasally.

## CONCLUSION

Utilization of vascularized pedicled flaps in extended endoscopic endonasal skull base surgery has been shown to significantly reduce the CSF leak rate for large dural defect and high-flow CSF leaks. The NSF continues to be the workhorse flap for the reconstruction of skull base defects due to its versatility. However, a variety of other vascularized flaps can be used in combination with the NSF for more extensive coverage or as an alternative when the NSF is unavailable. Knowledge of each flap's indications, limitations, and pitfalls is critical to prepare for successful endoscopic skull base surgery.

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# Minimizing Septectomy for Endoscopic Transphenoidal Approaches to the Sellar and Suprasellar Regions: A Cadaveric Morphometric Study

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## ABSTRACT

**Background:** Minimizing disruption of sinonasal anatomy may decrease morbidity from endoscopic endonasal approaches. The minimal amount of posterior septectomy required to provide sufficient access to the sphenoid sinus and sella has not been previously measured.

**Methods:** Under endoscopic visualization, wide bilateral sphenoidotomies were performed on ten cadaveric heads. Baseline measurements performed included the width of the posterior sphenoid sinus wall and inter-opticocarotid recess (interOCR) distance. Next, incremental 5mm posterior septectomies (5mm to 35mm) were performed and the horizontal exposure width and horizontal exposure angle were measured. Lastly, maximum lateral exposure following bilateral middle turbinectomies was measured.

**Results:** The mean baseline width and exposure angle of the posterior sphenoid sinus was 29.4 $\pm$ 3.7mm and 24.2 $\pm$ 2.80, respectively. The interOCR distance was 26.4 $\pm$ 4.8mm. Exposure increased progressively until a 20mm posterior septectomy was achieved. No significant increase in mean horizontal exposure ($P = 0.96$) and angle ($P = 0.70$) were gained with a posterior septectomy greater than 20mm. Bilateral OCRs were accessible with a 15mm posterior septectomy. The addition of bilateral middle turbinectomies did not significantly increase exposure of the posterior sphenoid sinus ($P = 0.90$).

**Conclusion:** This cadaveric study demonstrates that a posterior septectomy greater than 20mm does not increase access to the posterior sphenoid sinus wall. Bilateral access to the OCRs is typically sufficient for sellar pathologies and can be well achieved with a posterior septectomy of 15mm. Middle turbinectomy did not significantly increase lateral exposure within the sphenoid sinus.

## INTRODUCTION

The endoscopic endonasal approach (EEA) has offered an alternative to microscopic transnasal and transcranial approaches to the sella, suprasellar region, and anterior cranial base. Studies have documented that the EEA is safe and effective, and may offer less morbidity with quicker recovery.[12,13] The EEA offers wider visibility over microscopic techniques and avoids frontal lobe retraction often required for transcranial approaches. However, excessive removal of nasal structures can lead to poor sinonasal functional outcomes.[2,3,5,13,15] During a transsphenoidal approach, a posterior septectomy is performed to provide wider exposure and binarial access through the sphenoid sinus. The purpose of this study was to determine the extent of posterior septectomy required to gain adequate exposure of the sphenoid sinus and sella. Additionally, we sought to determine whether the addition of middle turbinectomies increased sellar exposure.

## MATERIALS AND METHODS

We performed an endoscopic endonasal morphometric study on ten cadaveric heads. Thin-slice (1.0 mm) sinus computerized tomography (CT) scans were performed for stereotactic navigation. Each cadaveric head was placed in rigid fixation and image registration was performed to less than 2mm deviation error and confirmed with anatomical landmarks. Dissection was performed using a 4mm, 0-degree, rigid endoscope with high-definition monitor and camera (Stryker, Kalamazoo, Michigan), as well as standard endoscopic instrumentation. Neuronavigation software (Stryker, Kalamazoo, Michigan) and a 15cm length stereotactic wand was used to obtain measurements.

### Dissection and Measurements

The middle turbinates were lateralized bilaterally. A wide sphenoidotomy was performed bilaterally to the limit of the medial orbit and from the planum sphenoidale to the floor of the sphenoid sinus. Sphenoid septae were removed and key anatomical landmarks were identified for the measurements (Figure 1a). Using the stereotactic navigation system, the distance was measured between the most lateral extent of the sphenoid sinus exposure through each corresponding naris, and is labeled the maximum horizontal exposure width (maxHEW) (Figure 1b). The rostro-caudal location of the HEW was defined as the mid-point between tuberculum sella and the floor of the sphenoid sinus (Figure 1b). In a similar fashion, the distance between each OCR was measured. These measurements served as baseline control for each cadaver.

We measured the horizontal exposure width (HEW) of the posterior sphenoid sinus, defined as the distance from the most lateral exposure of the sphenoid sinus to the contralateral side, as permitted by the nasal septum. After

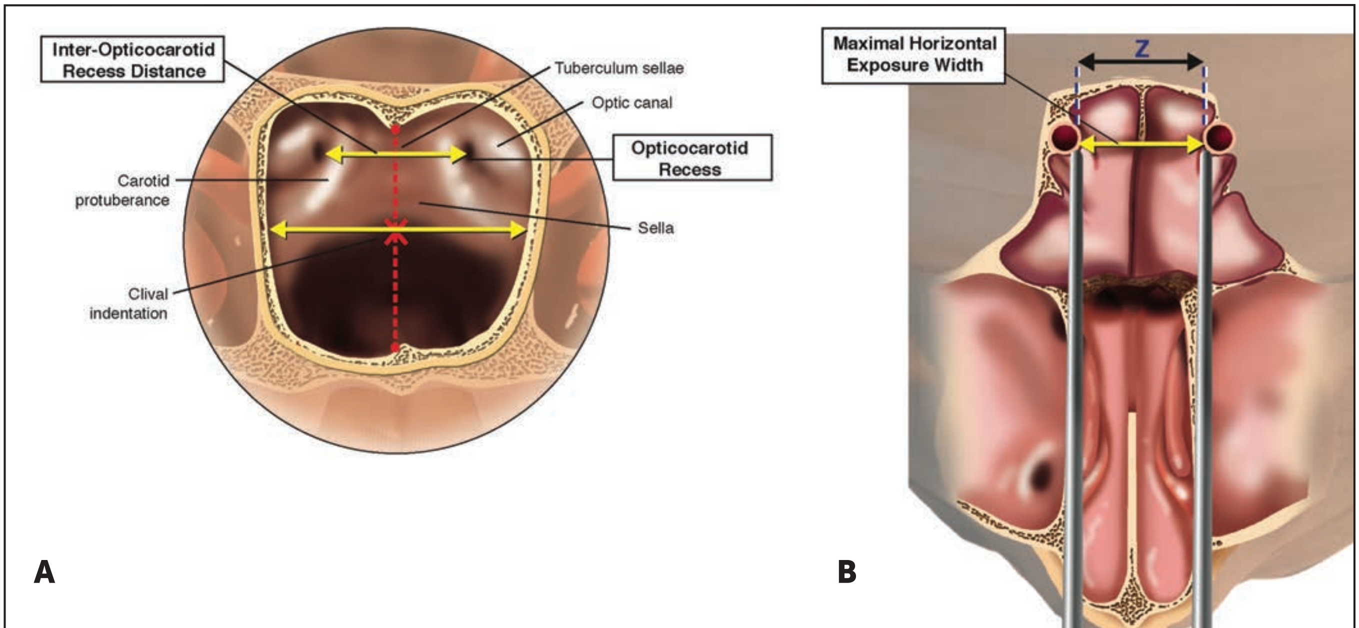


**Figure 1**

**A.** Coronal view of the posterior sphenoid sinus wall. Opticocarotid recesses, tuberculum sella, and sphenoid floor were identified. Exposure measurements were taken in a rostral-caudal line approximately midway between the tuberculum sella and sphenoid floor.
**B.** Axial view. The maximum exposure width (maxHEW) was taken to serve as a baseline measurement prior to septum resection.

each incremental septectomy, measurements were performed in each naris, thus providing twenty sets of measurements among the ten cadavers. The HEW was measured after successive posterior septectomies, performed at 5mm intervals (Figure 2). The distances between each pyriform aperture and the horizontal limits of the HEW were also measured to obtain our horizontal exposure angle (HEA) as a surrogate measurement of surgical freedom (Figure 2). As a final step, bilateral complete middle turbinectomies were performed and the lateral access from each naris was measured.

### Analysis and Statistics

The measurement of the HEW, along with distance a and b, allowed for the calculation of the horizontal angle of exposure (HEA) as follows: HEA = cos-1 (a2 + b2 - HEW2)/2ab. The HEWs and HEAs were compared between each successive amount of posterior septectomy using an ANOVA test with p-value less than 0.05 considered significant. A t-test used to compare maxHEW before and after middle turbinectomies.

## RESULTS

### Exposure with Septectomy

As demonstrated in figure 3, the HEW and HEA increased after the initial 5mm posterior septectomy. From 5 to 20mm of posterior septectomy, the HEW increased from 21.1 +/- 2.8mm to 28.7 +/- 3.2mm, and the HAE increased from 16.3 +/- 2.5mm to 23.3 +/- 3.0mm. Of note, a HEW equivalent to the mean OCR width was achievable with a septectomy of 15mm. No significant increase occurred in HEW (p=0.96) or HEA (p=0.70) with additional septectomy beyond 20mm.

### Middle Turbinectomy

After removal of bilateral middle turbinates, the HEW and HEA obtained were 29.6 $\pm$ 3.3mm and 24.4 $\pm$ 2.7degrees, respectively. There was no significant increase of exposure or surgical freedom by adding middle turbinectomies after 35mm posterior septectomy.

## DISCUSSION

Resection of the posterior septum and middle turbinates has been frequently advocated for better surgical access during endoscopic endonasal approaches to sellar and parasellar lesions.[11,12] However, aggressive resection of these structures may add significant rhinological morbidity.[2,3,5,10,13,15] A posterior septectomy permits instrument access to the contralateral side and may improve maneuverability within the sphenoid sinus (i.e. reaching the left OCR with instruments entering the right nare). The middle turbinate might limit access to the ipsilateral sphenoid sinus lateral recess and possibly the lateral working space through the ipsilateral naris. In our surgical experience, preservation or minimal disruption of these structures has been employed without the perception of impaired exposure or maneuverability. The impact of posterior septectomy and middle turbinectomy on sphenoid sinus exposure and surgical freedom has not previously been evaluated in the literature.

Using zero degree endoscopes, our results demonstrate that maximal exposure of the sphenoid sinus was achieved in all specimens with a posterior septectomy of 20mm. Beyond 20mm, no further increase in exposure or angle

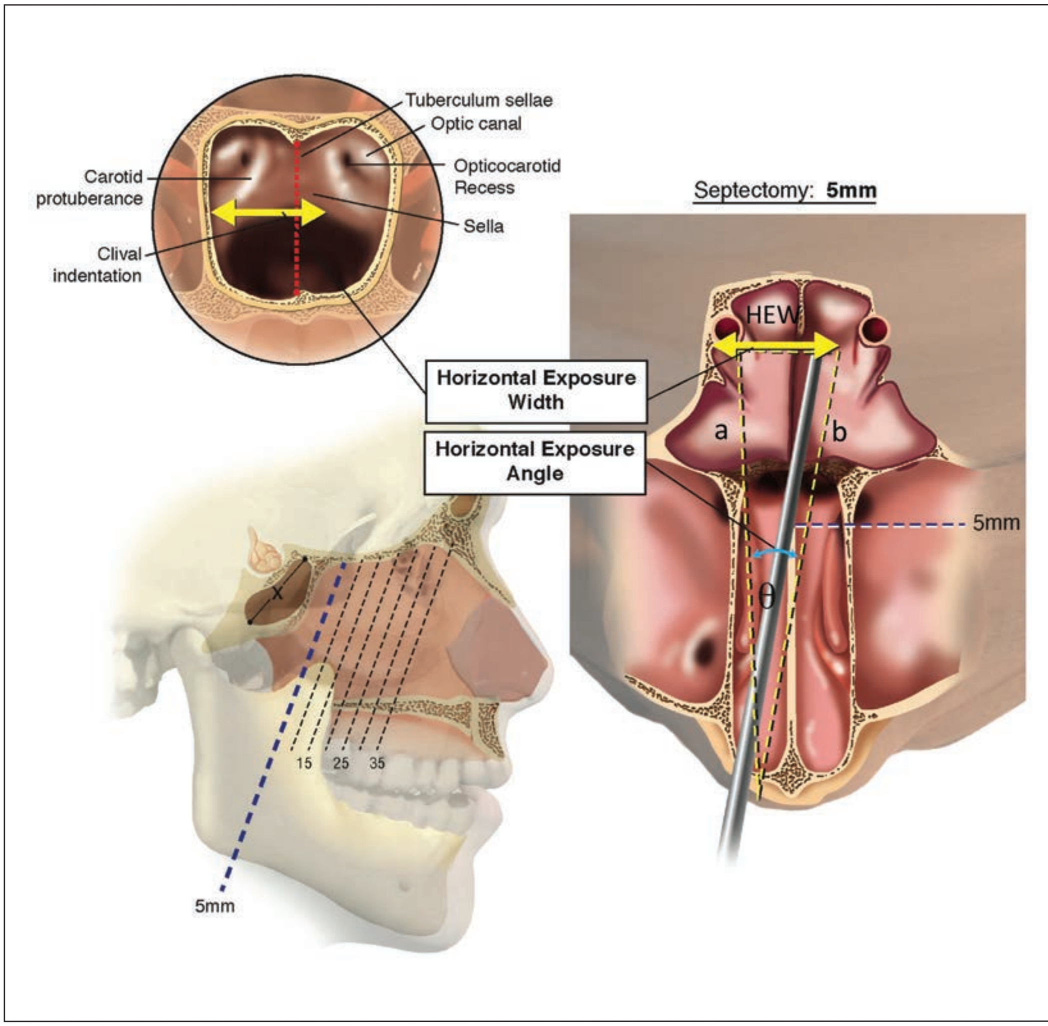


**Figure 2**

**Bottom left.** Posterior septectomy started at 5mm and increased by 5mm increments to 35mm.
**Top left and right**. After each septectomy, the horizontal width of exposure (HEW) and horizontal angle of exposure (HEA) were measured. Measurements a and b represent the distance from the pyriform aperture and used to calculate HEA.

of exposure was gained. Furthermore, bilateral visualization of the OCRs was achieved in all specimens following a septectomy of 15mm, suggesting that sufficient working exposure for the majority of sellar and parasellar pathologies may be achieved with a 15mm posterior septectomy. This is to our knowledge the first quantitative measurement to support that a small posterior septectomy will provide sufficient access to the posterior sphenoid wall. [11,14] The addition of middle turbinectomies at the maximal posterior septectomy of 35mm also failed to result in further increase of exposure. Although our study did not aim to measure the effect of middle turbinectomies on working space proximal to the sphenoid sinus, our data suggests that when accessing the lateral portions of the sphenoid sinus through the ispilateral naris (i.e. the right lateral OCR through the right naris), a complete middle turbinectomy may not add significant exposure. Lateralization of these structures should provide sufficient access to the sellar region.

Recently, studies analyzing quality of life (QOL) after endoscopic skull base surgery show that there is an initial post-operative worsening of sinonasal QOL, which gradually returns to pre-operative baseline by 6 to 12 weeks.[2,13] Crusting and anosmia are two sinonasal sequelae that impact quality of life and techniques to minimize these complications are important.[15] Although the majority of patients eventually achieve excellent recovery of sinonasal function, limiting resection of normal sinonasal structures may reduce postoperative rhinological morbidity and more rapid return of sinonasal QOL. Furthermore, preserving these sinonasal structures may be important so they are available for cranial base repair if reoperation is necessary in the future.

Although the results obtained in this cadaveric study were highly consistent, there are limitations to this study. Differences in tissue pliability between cadaveric specimens and actual patients are inherent to cadaveric studies. However, one would expect this decreased tissue pliability to reduce the exposure and surgical freedom obtained with septum and turbinate preservation. Additionally, while these results are most likely relevant when using 0-degree endoscopes and straight

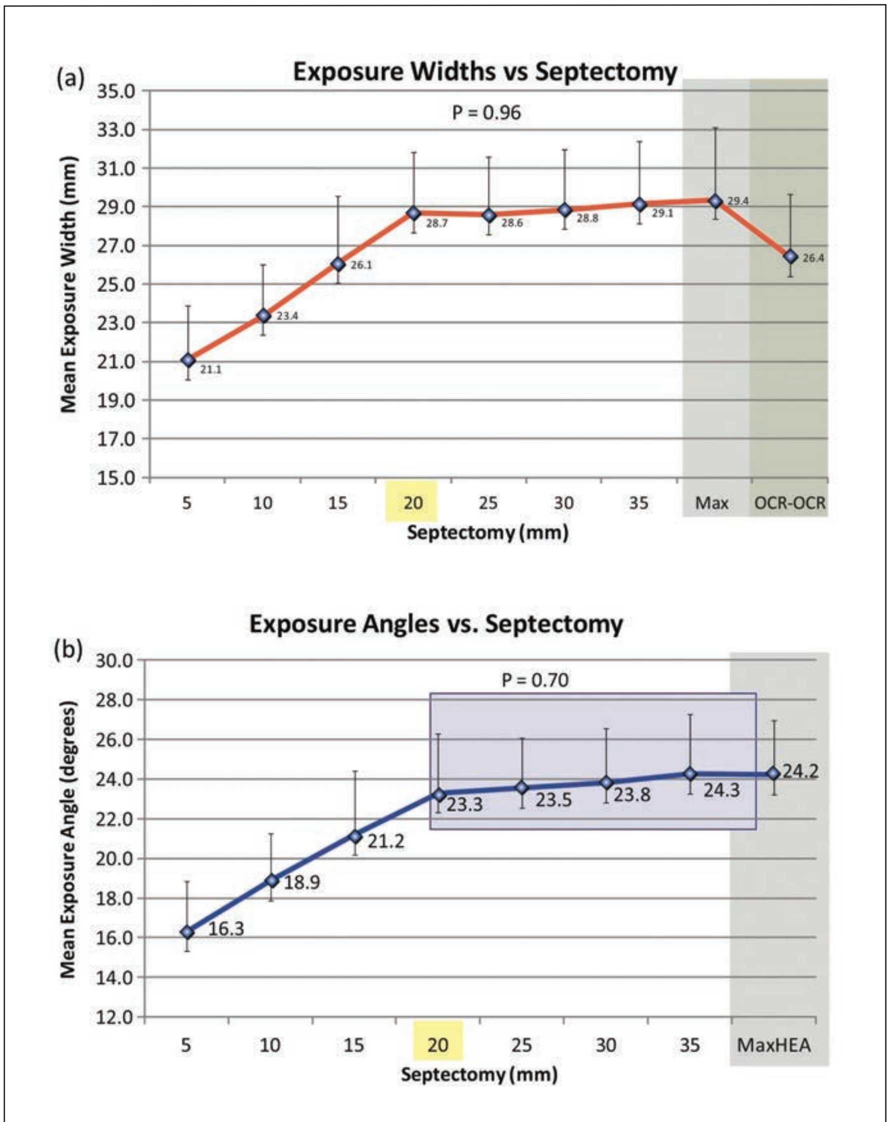


**Figure 3**

Graph demonstrating the effect of posterior septectomy on (**A**) HEW and (**B**) HEA. Mean maximum HEW (gray shade) and mean inter-OCR distance (green shade) are also shown for baseline comparison.

instrumentation, the use of angled instruments or endoscopes may allow adequate exposure of the sphenoid sinus and sella with even less tissue disruption. Individual anatomic factors including septal deviation, location of pathology, and shape of the sphenoid sinus need to be considered to tailor the exposure. Furthermore, although we found that middle turbinectomies did not increase lateral access through the ipsilateral naris, these measurements were obtained using an endoscope and single instrument after a 35mm posterior septectomy. Therefore, we are unable to extrapolate whether the middle turbinectomy could improve the HEW or HEA at the lesser degrees of septectomy. Finally, this study design could not adequately assess the impact of middle turbinectomies on instrument working space or maneuverability proximal to the sphenoidotomy.

## CONCLUSIONS

A posterior septectomy of beyond 20mm did not significantly increase exposure or surgical freedom of the posterior sphenoid sinus and sella. In fact, posterior septectomy of 15mm was sufficient for exposure of bilateral OCRs. The addition of middle turbinectomy to a 35mm posterior septectomy did not add to horizontal exposure of the sphenoid sinus from the ipsilateral naris. The impact of middle turbinectomy on instrument maneuverability remains to be assessed.

## DISCLOSURE

The authors 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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# Superior Turbinate Osteoplastic Flap (STOP) for Anterior Cranial Base Repair

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## INTRODUCTION

Resection of skull base tumors can often result in iatrogenic violation of the skull base creating defects of various sizes. Endoscopic sinus surgery and head trauma can also be a cause of skull base defects resulting in cerebrospinal fluid (CSF) rhinorrhea. Many of these defects will close spontaneously. Regardless of the etiology of the defect, closure of the skull base is necessary in the presence of persistent CSF leakage to avoid unwanted complications such as low-pressure headaches, pneumocephalus, and most importantly meningitis, which has a high rate of morbidity and mortality. There are many techniques available in the skull base surgeon's armamentarium for endoscopic repair of the skull base (see our review in this issue of the JHN Journal).[10]

Historically, repair of spontaneous skull base defects relied on local mucosal, free mucosal or free cartilage grafts for closure. Some examples of free mucosal grafts include autologous temporalis fascia, cadaveric fascia, pericardium, dermis, and allo-plastic collagen. Several series have demonstrated 95% success rate with use of various grafts for smaller defects.[7,8] Multilayered closure is an important concept in endonasal repair of defects after cranial base surgery. Vascularized local pedicled mucosal flaps have been shown to be the most effective in reducing postoperative CSF leak rates in extended endonasal skull base surgery.[4] Previously described techniques include a pedicled nasoseptal flap, a posterior pedicle inferior turbinate flap (PPITF), and a middle turbinate vascularized flap (MTF).[1,3,11] The ideal flap should be accessible, durable, and minimally destructive and many of the techniques mentioned above meet some or all of these criteria.

We devised a new flap that utilizes both autologous mucosa and bone for repair of the cranial base. The use of a superior turbinate osteoplastic (STOP) flap for endonasal repair of skull base defects has not been reported in the literature to our knowledge. This report describes the use of the superior turbinate as an osteoplastic flap for the repair of an anterior skull base defect after endoscopic endonasal resection of a cribriform encephalocele. The STOP flap is useful in a limited subset of patients and can serve as an adjunct to many of the traditional skull base reconstruction techniques.

## CASE PRESENTATION

A 44-year-old white female with no history of trauma or endonasal surgery initially presented with a 9 months' history of headaches, chronic left-sided nasal obstruction, and left-sided clear rhinorrhea. A non-contrast computed tomography (CT) of the paranasal sinuses demonstrated a 9 mm wide defect within the left ethmoid roof with abnormal soft tissue opacification extending through the defect into the left ethmoid sinus and occupying the left nasal cavity (Figure 1a). Magnetic resonance imaging (MRI) including pre- and post-contrast enhanced sequences of the paranasal sinuses demonstrated soft tissue and fluid collection associated with the defect consistent with an anterior basal meningoencephalocele (Figure 1b). Based on these findings, the patient was scheduled for endoscopic endonasal repair of the encephaolcele and cranial defect.

## TECHNIQUE

After induction of general anesthesia and prior to patient positioning, a lumbar puncture was done to check opening pressure and rule out elevated intracranial pressure as a cause for her encephalocele and CSF rhinorrhea. The opening pressure was normal at 14 centimeters of water. A lumbar subarachnoid drain was placed to help manage potentially elevated ICP in the immediate post-operative period due to the fact that the copious CSF rhinorrhea could make the ICP seem normal or low preoperatively. However, lumbar drains are not routinely used in our institution for endoscopic skull base cases. The patient was then positioned for an endoscopic approach to the anterior skull base with the head of bed elevated at 30 degrees and the STRYKER (Kalamazoo, MI) stereotactic navigation system was calibrated. The nasal mucosa was infiltrated with 1% lidocaine with epinephrine (1:100, 000) and 4% cocaine pledgets applied topically for added vasoconstriction.

First, the encephalocele was identified endoscopically (Figure 2) extending along the medial aspect of the middle turbinate and lateral to the superior turbinate. Both the middle turbinate and superior turbinate were carefully preserved. The mass was circumferentially dissected and followed to the skull base. After separation of the mass from the surrounding mucosa, the dural neck was identified, cauterized using endoscopic bipolar cautery and divided using endoscopic microscissors. Intraoperative frozen section pathology confirmed a meningoencephalocele. The bony defect was exposed circumferentially and intranasal mucosa was dissected

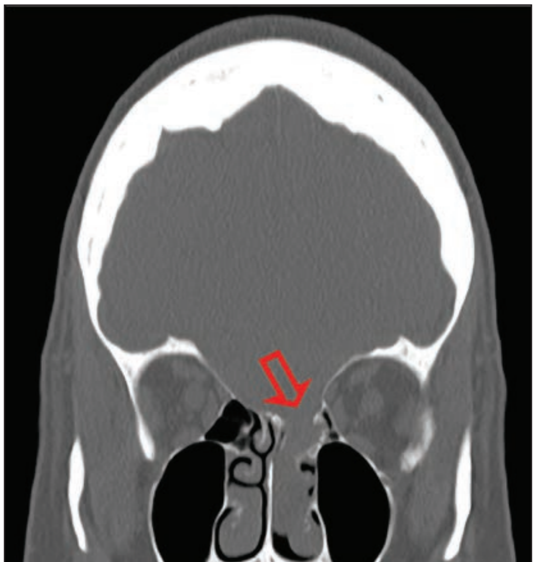

**Figure 1A**

Coronal computed tomography without contrast demonstrating soft tissue extending inferiorly from the left anterior cranial fossa, through a defect in the left cribriform plate, into the inferior left nasal cavity (arrow).

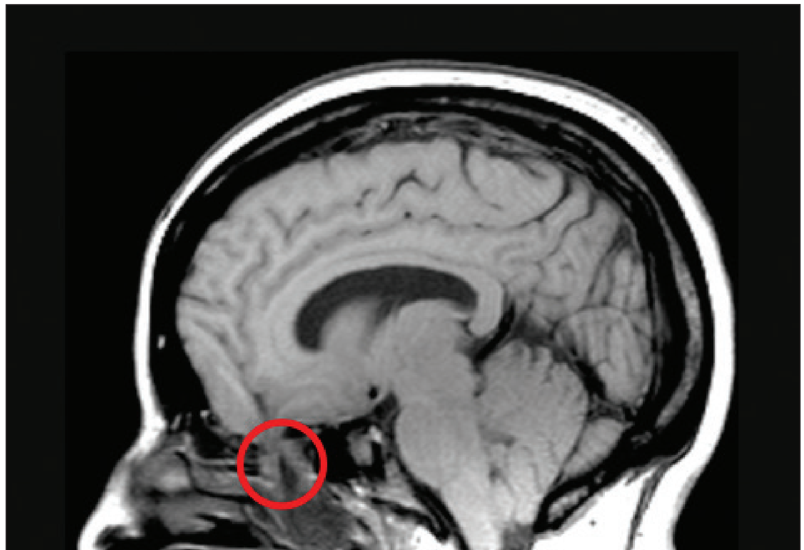

**Figure 1B**

Sagittal magnetic resonance image T1 weighted pre-contrast demonstrates herniation of CSF and the left gyrus rectus (circle) through the defect.

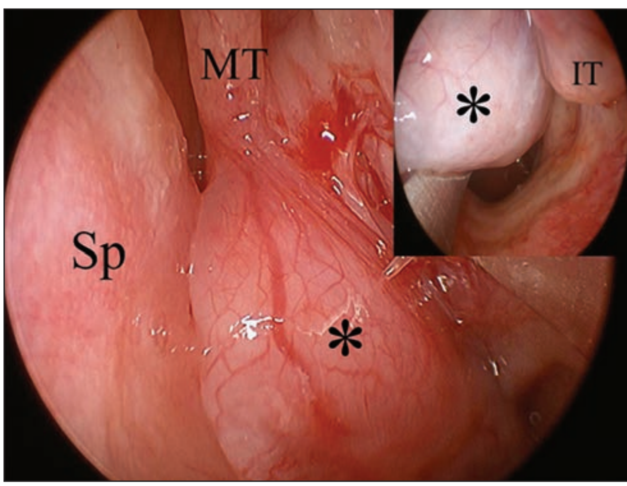


**Figure 2**

Endoscopic view of left nasal cavity with zero degree endoscope demonstrating white soft tissue mass (asterisk) emanating medial to middle turbinate (MT), extending down to just above floor of nasal cavity. (IT, inferior turbinate; Sp, septum.

away from the bony defect for at least 5mm.

A sheet of collagen matrix (Duragen, Integra LifeSciences Corporation, Plainsboro, NJ) was placed within the defect as an inlay dural repair. Next, an onlay sheet of collagen matrix was placed along the epidural surface of the defect. The intended option for intranasal reconstruction was a left-sided nasoseptal flap, however the mucosa was very thin and less robust than expected, likely due to chronic compression by the large meningoencephalocele. Because of the healthy appearance of the superior turbinate and the close proximity to the defect, the decision was made to mobilize and utilize superior turbinate for intranasal reconstruction (Figure 3). The lateral half of the superior turbinate mucosa was carefully removed with preservation of the underlying bone. The vascularized osteoplastic flap was then reflected into position across the primary dural repair and covered the entire anterior cranial-base defect well (Figure 4). Care was taken to ensure that no local mucosa was covered by the STOP flap to avoid the risk of mucocele. A small amount of polyethylene glycol hydrogel matrix (DuraSeal, Covidien, Mansfield, MA) was applied over the repair. No intranasal packing was used.

## DISCUSSION

Endoscopic endonasal surgery is becoming increasingly popular for resection of anterior skull base masses and repair of skull base defects. Most important considerations in any reconstruction is a stable primary dural reconstruction covered by a nasal mucosal graft, preferably vascularized. [12] The exact choice of repair technique utilized depends on several factors such as the type of resection, available material, and ultimately the size and location of the defect. Free grafting is highly successful for small, low-flow skull base defects with a minimal incidence of postoperative CSF

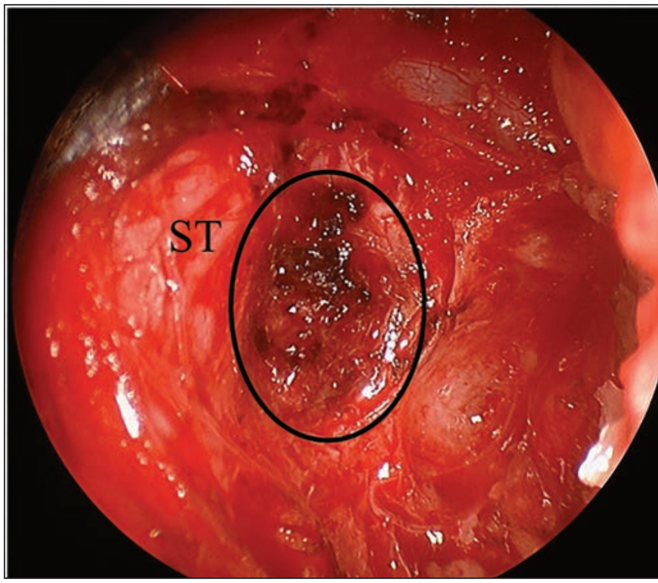


**Figure 3**

Mobilized superior turbinate (ST) and cauterized surface of skull base defect (circle).


**Figure 4**

Coverage of anterior cranial base defect with rotated superior turbinate osteoplastic flap (STOP).

leak.[5] With larger defects, a vascularized local pedicled flap as an overlay has been shown to be more effective in reducing postoperative CSF leak rates and may promote faster and more complete healing.[4]

Currently, the workhorse flap is the pedicled nasoseptal flap, which is a mucoperiosteal and mucoperichondrial flap of the nasal septum based on the nasal branch of the sphenopalatine artery. The nasoseptal flap reported by Hadad et al has been shown to be effective for large cranial base defects and maybe particularly useful in cases where adjuvant radiation therapy has been used or is anticipated.[3] More importantly, the use of this flap resulted in a lower incidence of post-operative CSF leaks.[3] Another useful flap for the overlay portion is the middle turbinate flap, which has been shown to be effective as a free mucosal graft, composite bone/mucosal graft, or as a donor site for separate bone and mucosal grafts.[9] Vascularized middle turbinate flap has been used when nasoseptal flap is not available and has been shown to be as effective as the nasoseptal flap.[11] PPITF has been used as a useful alternative, but because of its location it has limited coverage of anterior cranial base defects.[2]

The use of the superior turbinate flap as an osteoplastic flap to our knowledge has not been reported in the literature. As part of the ethmoid bone, the superior turbinate is located on the lateral nasal wall above the middle turbinate. Blood supply to lateral nasal wall is from branches of the sphenopalatine artery and the posterior ethmoid artery posteriorly and branches of the angular artery and the anterior ethmoid artery anteriorly. According to the cadaveric study of sphenopalatine artery by Lee et al, the feeding vessels of the superior turbinate were from the septal artery in 72%, from the posterior lateral nasal artery in 18%.[6] However, their study is limited to sphenopalatine artery so further anatomic studies are needed to detail the blood supply of superior turbinate. There is a rich anastomotic network of anterior ethmoid and posterior ethmoid vessels. We believe that preservation of vessels during the procedure, such as the anterior ethmoid and sphenopalatine artery, will result in maximal blood supply to the superior turbinate flap. Injury to these vessels from previous surgery, trauma, or embolization may compromise the blood supply to the superior turbinate.

One major advantage for the use of the superior turbinate osteoplastic (STOP) flap for endonasal skull base reconstruction is the close proximity to the anterior skull base. In our case, the nasoseptal flap was very thin and not robust enough to adequately provide multilayered closure of the skull base. Based on proximity and excellent blood supply, the superior turbinate is excellent for defects of this nature. Another potential advantage is the composite nature of the flap with the superior turbinate bone and mucosa. This eliminates the need for a separate incision to harvest fat or fascia and obviates the need to use additional autologous or synthetic buttress material. The inclusion of the

**Figure 5**

Postoperative non-contrast computed tomograph demonstrating closure of the anterior skull base with bone and mucosa of the STOP flap (arrow).

turbinate bone provides additional rigidity to the flap and provides both vascularized autologous bone and mucosa for reconstitution of the normal layers of the cranial base. Lastly, bilateral superior turbinates can be used for bilateral or central anterior cranial base defects when the superior nasal septum is involved or compromised.

The STOP flap has some limitation because the presence and size of the superior turbinate is variable among individuals. Moreover, the pedicled nature of the flap to preserve the blood supply limits the arc of rotation for more lateral or posterior cranial base defects. It is also important to remove all mucosa from the lateral surface of the turbinate prior to rotation of the graft into place to prevent a post-operative mucocele formation. In our patient, follow-up at 15 months revealed the STOP flap to be in good position and well incorporated into the skull base without evidence of mucocele formation (Figure 5).

## CONCLUSION

The superior turbinate osteoplastic (STOP) flap is a composite vascularized, autologous bone and mucosa flap, which should remain in the endonasal surgeon's armamentarium for repair of anterior cranial base defects. The proximity to the skull base and robust blood supply make it an appropriate choice for small anterior skull base defects as part of multilayered closure.

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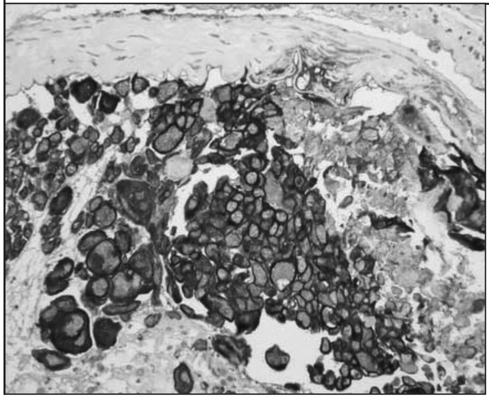

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