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Closure of large skull base defects after endoscopic transnasal craniotomy

Clinical article

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Object. The authors describe the utility of and outcomes after endoscopic transnasal craniotomy and skull reconstruction in the management of skull base pathologies.

Methods. The authors conducted a observational study of patients undergoing totally endoscopic, transnasal, transdural surgery. The patients included in the study underwent treatment over a 12-month period at 2 tertiary medical centers. The pathological entity, region of the ventral skull base resected, and size of the dural defect were recorded. Approach-related complications were documented, as well as CSF leaks, infections, bleeding-related complications, and any minor complications.

Results. Thirty consecutive patients were assessed during the study period. The patients had a mean age of 45.5 ± 20.2 years and a mean follow-up period of 182.4 ± 97.5 days. The dural defects reconstructed were as large as 5.5 cm (mean 2.49 ± 1.36 cm). One patient (3.3%) had a CSF leak that was managed endoscopically. Two patients had epistaxis that required further care, but there were no complications related to intracranial infections or bleeding. Some minor sinonasal complications occurred.

Conclusions. Skull base endoscopic reconstructive techniques have significantly advanced in the past decade. The use of pedicled mucosal flaps in the reconstruction of large dural defects resulting from an endoscopic transnasal craniotomy permits a robust repair. The CSF leak rate in this study is comparable to that achieved in open approaches. The ability to manage the skull base defects successfully with this approach greatly increases the utility of transnasal endoscopic surgery. *(DOI: 10.3171/2008.8.JNS08236)*

Key Words • cerebrospinal fluid leak • endoscopy • flap • reconstruction • skull base

Substantial advances in SBS have been made in the past decade. There are endoscopic approaches to the entire ventral skull base, and the diversity of pathologies treated endoscopically has grown substantially.[27,28,34,36,38,39] Along with managing cerebrovascular structures, the repair of a large skull base defect resulting from endoscopic transnasal craniotomy remains a difficult challenge. Problems with closure of the dura mater and prevention of CSF leaks are a persistent source of complications in both endoscopic and open SBS; these problems have even been described as the Achilles heel of endoscopic SBS.[23]

Small defects and CSF fistulas have an excellent rate of closure via an endoscopic technique. A > 90% closure rate with primary endoscopic surgery and a 97% closure rate with endoscopic revision are possible.[18] Most published reports on these techniques describe the use of free grafts. Defects in the skull base that result from resection of neoplasms and intracranial tumors and the repair of encephaloceles are much larger. Reported case series of endoscopic SBS, with extensive bone removal and subsequent intradural surgery, have generally described much higher rates of CSF leaks.[9,11,13,23,26] A variety of reconstructive techniques have been described.[2,11,12,20–22,24] The use of multilayered free grafts was previously popular among surgeons with endoscopic skull base experience.[9,13,21,24]

Over the past decade, the use of vascularized mucosal pedicled flaps has been the most significant ad-

Abbreviations used in this paper: SBS = skull base surgery; SPA = sphenopalatine artery.

vancement at our institution in the reconstruction of major endoscopic skull base defects. The use of vascularized reconstructive tissues has significantly improved closure and wound complication rates in open skull base surgery.[19,30,35] We currently use vascularized pedicled nasal mucosal flaps during transnasal transcranial surgery whenever possible. Pedicled mucosal flaps have been well described for a variety of reconstructive procedures such as septal perforation repair,[31,33] reconstructive rhinoplasty,[3,29] and choanal atresia repair.[10,37] However, the use of vascularized mucosal flaps to repair large skull base[16] or congenital defects[40] has been only recently described. Along with practitioners at other centers with endoscopic skull base experience, we discourage the use of large free bone grafts and synthetic materials (such as titanium mesh) as these may lead to poor healing and the formation of sequestra.[21]

Endoscopic SBS has evolved at many institutions from experience in sinus surgery, meningoencephalocele repair, CSF leak closure, and the management of pituitary adenomas. Minimal tissue dissection or bone removal and the preservation of dura mater at all costs is often emphasized in these procedures. In retaining these principles, many central skull base lesions are managed through small sphenoidotomies (to preserve closure options), limited openings in the skull base (usually just the sellar floor or small cribriform openings), and minimal dural resection. Subsequently, dissection proceeds with poor instrument access, blunt curette dissection, a single-surgeon operator, and the need for angled endoscopes to view the pathology. The use of a wide surgical access via an endoscopic transnasal craniotomy allows resection with surgical techniques similar to those used in open procedures. Based on our experience in > 200 endoscopy cases, we believe that this wide access greatly enhances the capabilities of the surgical team (Fig. 1). In the present study we describe the surgical outcomes and technique used to close large skull base defects after large transnasal craniotomy.

Methods

Patient Population

The charts of all patients who underwent a totally endoscopic approach to cranial base pathologies at 2 skull base surgical centers between March 2007 and March 2008 were reviewed. Inclusion criteria were as follows: 1) a totally endoscopic approach was used; 2) intradural dissection was performed; and 3) the patient underwent pedicled vascularized flap reconstruction of the skull base defect. All procedures were performed at 2 tertiary referral centers: Hospital Edmundo Vasconcelos, Sao Paulo, Brazil, and the Medical University of South Carolina. The study received institutional review board approval at both institutions.

A range of pathologies are treated endoscopically at these institutions, and the classification of approaches both to the midline and lateral to the ventral skull base is as listed in Table 1. This follows a scheme previously published in the literature.[34] Previous surgical approaches were classified as transcraniotomy, open transsphenoidal, or endoscopic. The size of the defect, as measured by its longest axis, was also recorded (Fig. 2). The type of pedicled flap used (discussed below) was also recorded.

Outcomes Assessed

Information on approach-related complications, mainly CSF leakage and infectious and bleeding events, was collected on data sheets. Infection-related complications

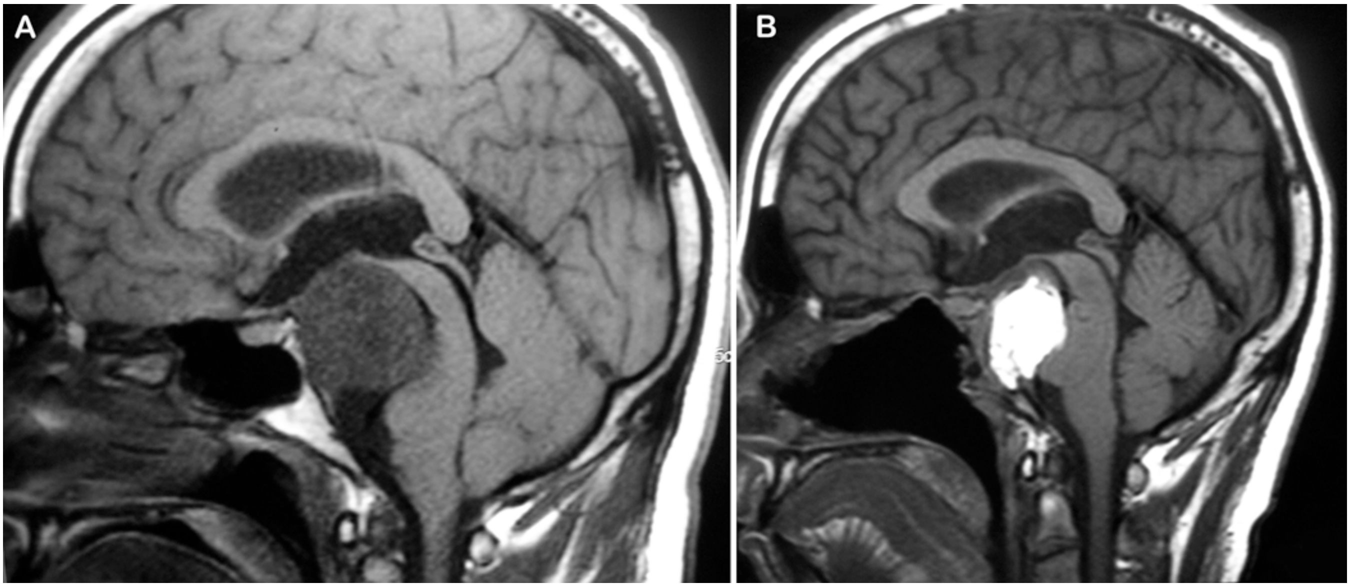

Fig. 1. Preoperative (A) and postoperative (B) MR images demonstrating endoscopic resection of a clival chordoma with a large intradural component, possible via a large transnasal craniotomy. Fat used in the reconstruction is visible in the postoperative image.

TABLE 1: Classification of endoscopic approaches*

Sagittal or Midline	Lateral
transfrontal	transorbital
transcribriform	petrous apex (medial transpetrous)
transplanum	lateral transcavernous
suprasellar/subchiasmatic	transpterygoid
transsphenoidal	transpetrous
sellar/medial transcavernous	superior
transclival	inferior
posterior clinoid	transcondylar
mid-clivus	parapharyngeal space
foramen magnum	
transodontoid	

* From Snyderman C, Kassam A, Carrau R, Mintz A, Gardner P, Prevedello DM: Acquisition of surgical skills for endonasal skull base surgery: a training program. **Laryngoscope 117:**699–705, 2007.

were defined as meningitis/ventriculitis, sinusitis, or a subdural abscess. Complications related to bleeding included epistaxis, for which additional packing or operative intervention was required, and subdural hematoma formation. Perioperative deaths were recorded. Minor complications we looked for included significant crusting or synechia formation that required formal intervention and evidence of possible encephalocele formation on long-term follow-up.

Surgical Technique

Anticipating the Size and Location of the Defect. The use of pedicled mucoperiosteal/mucoperichondrial flaps requires careful preoperative planning. An early injudicious posterior septectomy can easily rob the surgeon of a valuable graft. There are 4 pedicled nasal mucosal flaps that we recognize as options for reconstruction in endoscopic SBS (Fig. 3): 1) posterior rotation septal flap (based on the septal branch of the SPA); 2) the contralateral transposition septal flap (based on ethmoidal arteries); 3) the inferior turbinate flap (based on the turbinate branch of the SPA); and 4) the nasal floor flap (based on branches of the SPA and the Woodruff plexus).

In revision surgeries, the use of pedicled or free mucosal grafts might be hindered by previous septum or turbinate removal. The loss of reconstructive options may be considerable and must be identified preoperatively.

Flap Elevation. The flap is raised unilaterally or bilaterally at the beginning of the surgery. If septoplasty is anticipated, then a Killian incision may be more appropriate than a hemitransfixion. This will avoid a short mucosal segment between incisions if a very large flap has to be raised. A large posterior rotation flap is often raised from a point starting near the head of the inferior turbinate. A monopolar ball tip diathermy is used to mark out the vascular pedicle across the superior margin of the choana, the septal margins, and the lateral limit on the floor of the nose. Preparing an oversized flap for the defect is important because considerable flap length is lost by contouring the repair to the skull base (Fig. 4D). Extensive bone or cartilage removal from a previous septoplasty may make the elevation of flaps difficult.

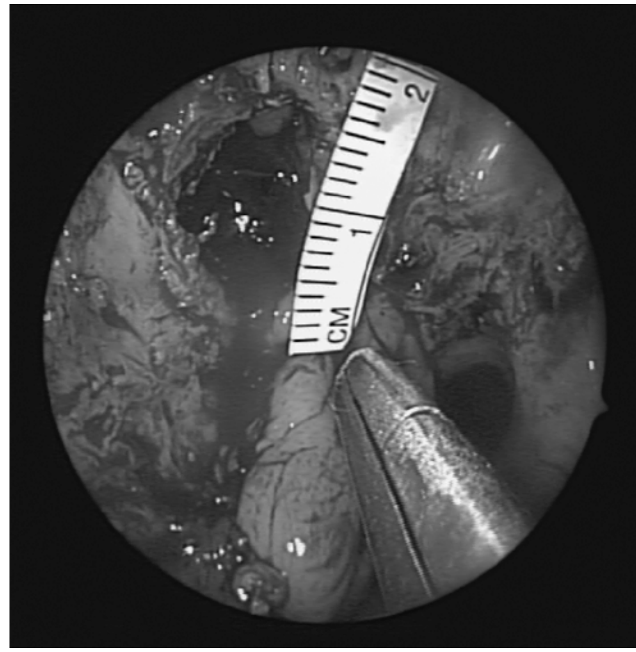

Fig. 2. Intraoperative photograph showing measurement of a dural defect. The defect measured was the dural resection not the total bone resection, which is usually larger.

Care of Flaps During Subsequent Surgery. Nothing is more disheartening at the end of a long skull base procedure than to discover that the flap has been inadvertently devascularized by injury to the pedicle. Thus great care must be taken to protect the graft as it is harvested at the beginning of endoscopic SBS. The flaps are guarded from subsequent trauma by relocating them to the ipsilateral maxillary sinus (Fig. 4B) or nasopharynx until use in later reconstruction. Gelfoam is placed over the exposed periosteum of the pedicle to prevent localized excoriation (Fig. 5D). Constant awareness of the pedicle location and proximal arterial segments must be maintained if dissection continues into the infratemporal fossa. If resection of the middle turbinate is required, its final removal should occur in the middle of the transverse segment to preserve the SPA and its branches.

Reconstruction Surgery. A free fat graft or DuraGen layer is used to fill the dead space (Fig. 1); a single piece of fat is used if possible. There is a theoretical risk of hydrocephalus if small fat grafts migrate into the third ventricle or subarachnoid space and occlude CSF flow. The fat graft forms a buttress for a subdural (or intracranial extradural graft) fascia/DuraGen graft (Fig. 4C). The intracranial fat/fascia/DuraGen complex is covered with a combination of pedicled mucosal flaps (Fig. 4D and 5D). Fibrin tissue glue is used to secure the repair and Gelfoam is layered to the area. The Gelfoam is supported with a Foley balloon catheter and gauze packing (Fig. 6) or alternatively a larger balloon (Epistat, Medtronic; Fig. 7).

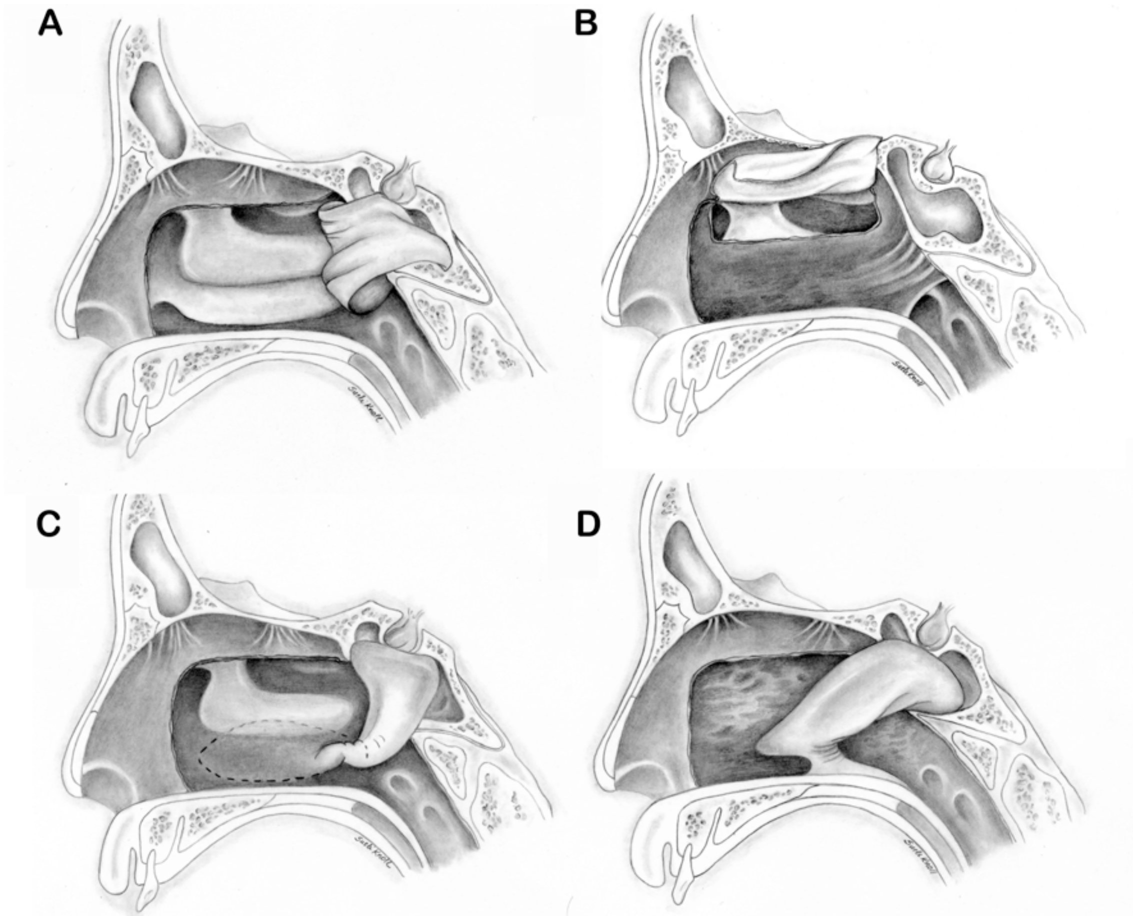

Fig. 3. Artist's illustrations of the various flap types. A: Posterior rotation septal flap. B: Contralateral transposition septal flap. C: Inferior turbinate flap. D: Nasal floor flap.

Free mucosal grafts may be used to augment the repair if the size of the defect has been underestimated. However, it should be stressed that mucosal flap development should always be oversized to allow for skull base contouring. Attempts to bridge the flaps across the natural contour of the skull base will only lead to the formation of dead spaces with subsequent poor healing, hematoma formation, and an increased risk of infective complications.

When packing with Gelfoam, placement that starts at the proximal or lowest aspect of the flap will avoid accidental repositioning. Tight packing should be avoided as this may compromise the vascular supply. We believe it is multilayered repair that prevents CSF leaks and not pressure applied from underneath. The pressure exerted from the packing material would rarely be so uniformly applied as to prevent CSF migration. A video is available online that demonstrates the creation of pedicled septal mucosal flaps, the endoscopic approach, and reconstruction of a large anterior cranial fossa meningioma.

Postoperative Care. Computed tomography scanning is performed at our institution on the 1st postoperative day to assess for hemorrhage. Antibiotics are used perioperatively and continued postoperatively while nasal packing remains in situ. Packing is left in place for 7–14 days as most grafts are adherent to bone within a week.[32] Patients are confined to bed/chair rest with toilet privileges for 48 hours, have 30° head elevation, and are advised to avoid straining, Valsalva maneuvers, and nose blowing. Either thromboembolic stockings or pneumatic calf compressors were used for venous thrombosis prophylaxis. Lumbar drains are not used unless there is an additional comorbidity such as raised intracranial pressure or prior radiotherapy. Balloon packing support is removed at 36–48 hours. If gauze packing was used, then this is removed at the first follow-up in 7–14 days. Patient discharge usually occurs at 3–5 days postoperatively and is usually a product of tumor type (endocrine disturbances) and patient comorbidities. Magnetic resonance imaging is performed early for baseline assessment (usually 3 months for benign disease). This is important as postsurgical MR imaging signaling is often difficult to interpret.[1]

Results

Thirty patients with a mean age of 45.5 ± 20.2 years underwent surgery during the study period; 43% of pa-

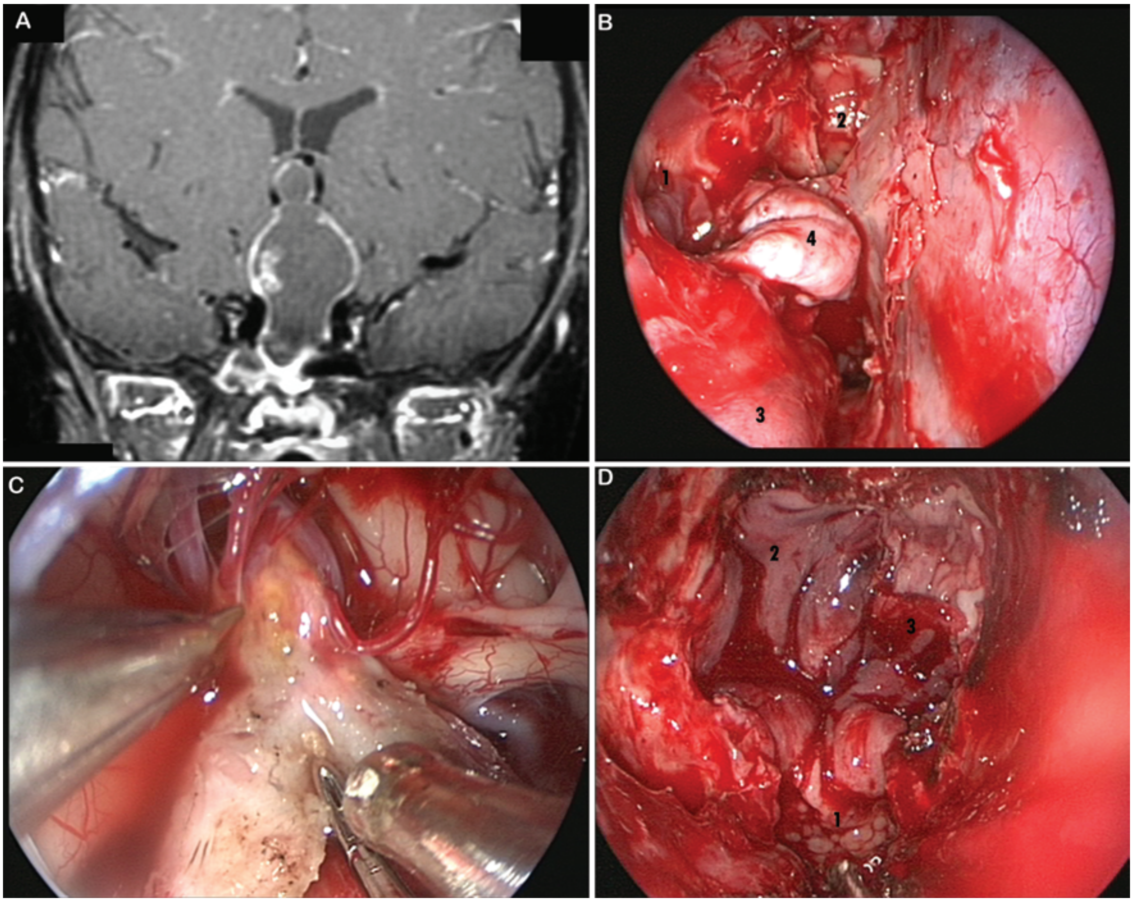

FIG. 4. Images obtained in a 6-year-old girl with a large craniopharyngioma. A: Preoperative coronal MR image. B: Endoscopic view of the approach and development of the nasal septal flap. 1 = right maxillary sinus; 2 = right sphenoid sinus; 3 = right inferior turbinate; 4 = a large pedicled septal flap reflected into the maxillary sinus. C: Intraoperative view of intradural sharp dissection performed by 2 surgeons. D: Endoscopic view of the pedicled septal flaps during reconstruction. 1= nasopharynx; 2 = right septal flap; 3 = left septal flap with an additional free mucosal graft superiorly.

tients were women. The mean follow-up in these patients was 182.4 ± 97.5 days. The diversity of pathological entities treated via a transnasal craniotomy is presented in Table 2. The CSF leaks included 2 postsurgical defects of 2 and 4.5 cm with extensive arachnoid disruption. The other CSF leak was in a patient with benign intracranial hypertension and an unusual defect inferior to the petroclival carotid artery with CSF leakage into the submucosal space of the nasopharynx.

The regions exposed are listed in Table 3. The size of defects ranged from 0.5 to 5.5 cm with a mean of 2.49 ± 1.36 cm; 83% (25) of defects were > 1.5 cm. Of the remaining 5 defects, 3 were located in the posterior fossa and 2 were open to the suprasellar cistern. Pedicle flap repair was considered appropriate for these high-flow defects < 1.5 cm. Previous surgery was performed via craniotomy in 6, an open transsphenoidal approach in 1, and endoscopically in 3 patients. In the majority of patients (28 of 30) the posterior-based septal flap was used (Fig. 4). In the remaining patients, the inferior turbinate was used in 1 (Fig. 5), and a contralateral flap was also used. Bilateral flaps were required in 8 patients (27%) to close the subsequent defect created.

The CSF leak rate was 3.3%. One patient underwent endoscopic treatment after a CSF leak developed in the immediate postoperative period. Primary resection of a planum sphenoidale meningioma was performed in a 62-year-old woman with no history of previous radiotherapy or any other medical comorbidity. Surgicel used for hemostasis in the superior intercavernous sinus was left in situ during the reconstruction and prevented direct apposition of the DuraGen to the edge of the defect. A CSF leak was suspected on the 1st postoperative day. A lumbar drain was placed postoperatively and clamped 48 hours later with subsequent recurrence of leakage. Endoscopic reexploration on postoperative Day 5 revealed the leaking area next to the Surgicel. The remaining reconstruction was intact (a 5.5-cm defect). The Surgicel was removed, DuraGen was reapplied to this area, and 1 of the septal flaps returned. No further leaking occurred.

The incidence of infectious complications was very low. There were no episodes of meningitis or subdural ab-

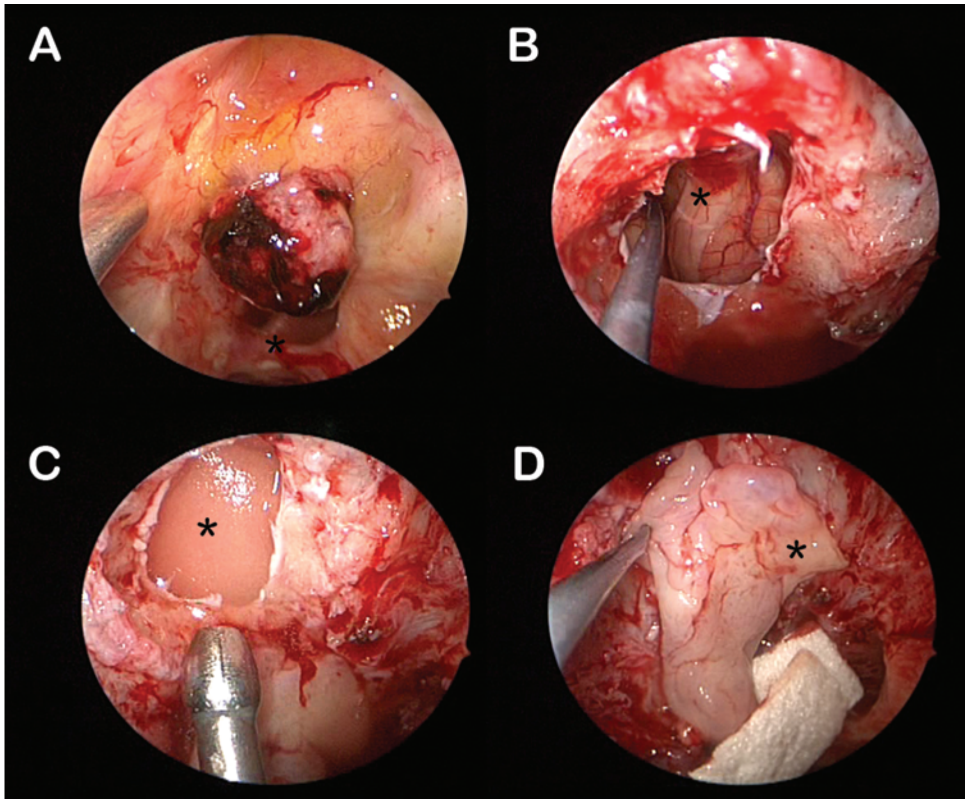

Fig. 5. Endoscopic views in a patient with recurrent adenocarcinoma of the ethmoid roof. A: Recurrent adenocarcinoma of the ethmoid roof. B: Transdural resection that included resection of the olfactory bulb and tract *(asterisk)*. C: DuraGen subdural layer *(asterisk)*. D: Inferior turbinate flap *(asterisk)* covering the defect. A previous septectomy had been performed. Printed with the permission of the author.

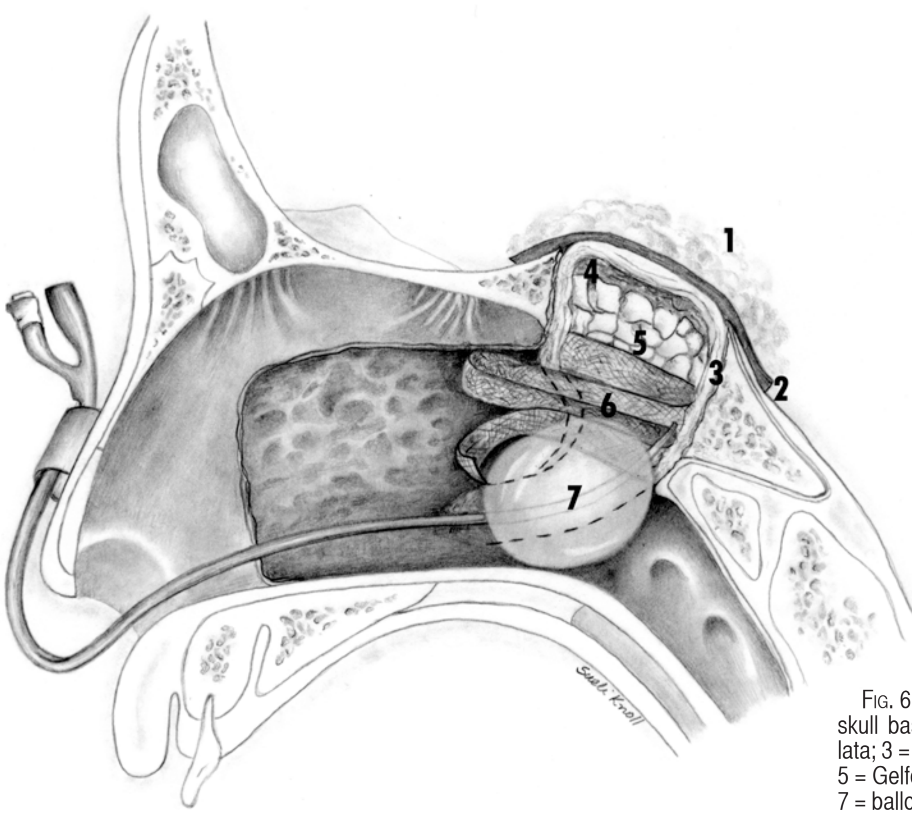

Fig. 6. Artist's illustration of the multilayered skull base reconstruction. 1 = fat; 2 = fascia lata; 3 = pedicled mucosal flaps; 4 = fibrin glue; 5 = Gelfoam; 6 = antibiotic impregnated gauze; 7 = balloon support.

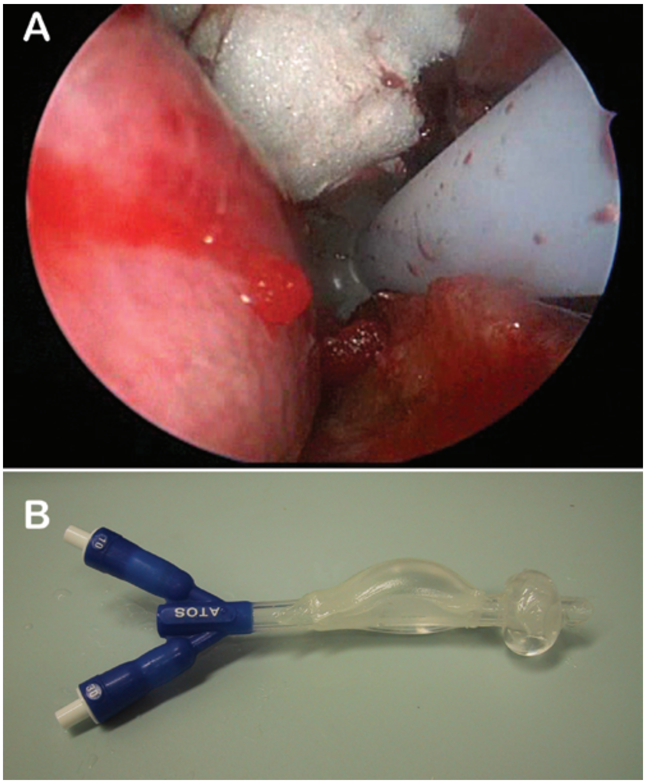

Fig. 7. A: Intraoperative endoscopic view of the EpiStat balloon pack with Gelfoam as an alternative to using a Foley catheter balloon and gauze. B: The EpiStat with both balloons partially inflated.

TABLE 2: Summary of reasons for endoscopic transnasal craniotomy in 30 patients

Pathological Entity	No. of Patients
CSF leak	3
pituitary adenoma	8
fibroosseous lesion	1
meningioma	3
craniopharyngioma	4
sinonasal malignancy	3
esthesioneuroblastoma	3
chordoma	4
metastasis	1

scess. Maxillary sinusitis (possibly related to packing) requiring medical therapy developed in 1 patient. Bleeding complications were seen in 2 patients (7%) with epistaxis, and 1 of these patients required inpatient care for significant bleeding from the cut septal edge. No episodes of subdural hematoma were noted.

Other minor complications included crusting. Nine patients (30%) had crusting that required otolaryngological care in an outpatient clinic setting; no patient required formal debridement. There was 1 sphenoid mucocele that was managed endoscopically 10 months postoperatively. Two patients had frontal recess obstructions that required endoscopic frontal sinus surgery as a delayed intervention. There were no episodes of clinically evident deep venous thrombosis, and no encephalocele formations or perioperative deaths in the patient population. In total, 4 patients (13.3%) required a second surgery: 2 required emergency surgery (for epistaxis and a CSF leak), and 2 required delayed outpatient surgical interventions.

Discussion

Endoscopic free graft reconstruction of large skull base defects has been achieved reliably in some series.[21,25] Good healing with CSF leak rates of 4% is reported; however, the numbers in these series are small. Hadad et al.[16] have recently reported on a rotation pedicled septal mucosal flap (similar to Fig. 5) for closing skull base defects. They reported a 4.5% CSF leak rate and 0% flap loss rate in 44 cases. This is comparable to the 3.3% leakage rate in our 30 cases. Any novel reconstructive technique should have a local wound complication rate not exceeding 20% to be in line with those reported in the international collaborative study of craniofacial surgery.[14] Similarly the CSF leak rate should ideally be < 10%, the failure rate reported from a meta-analysis on primary endoscopic fistula repairs.[18] Additionally, the long-term prevention of intracranial infective complications is excellent with the endoscopic layered repair. A recent study by Harvey et al.[17] has described a 0.9% risk of subsequent intracranial complications with a delayed CSF leak rate of 1.9% in 106 endoscopic skull base repairs over a 5-year period.

The use of vascularized grafts is generally considered to provide a more robust repair than free grafts.[30,35] Free vascularized grafts have been used to reconstruct craniofacial defects in complex and postradiotherapy cases with similar rates to nonvascularized repairs.[4,8,41] The complications related to the use of vascularized versus nonvascularized repairs were compared in the international collaborative study of craniofacial surgery in 1025 open cases. There was no difference in outcomes, but the analysis did no control for defect size, which would naturally preselect patients to each group.[15] The advantages of using a pedicled mucosal flap repair include the closure of

TABLE 3: Regions exposed in this series

Exposure	No. of Patients (%)
sagittal	
transcribriform	30 (100)
transplanum/transsphenoidal	16 (53.3)
transclival	4 (13.3)
transodontoid	1 (3.3)
lateral	
midline only	28 (93.3)
transorbital	1 (3.3)
lateral transcavernous	1 (3.3)

large defects (> 5 cm), less crusting with primary healing, less bone exposure, and a reliable and robust repair for postradiotherapy cases. There are some adverse effects that need to be considered when choosing this type of repair. The use of large pedicled mucosal flaps can significantly disrupt normal nasal physiological characteristics, potentially increase the risk of bleeding due to additional mucosal incisions, increase the risk of mucocele or frontal recess obstruction, and further disrupt the olfactory epithelium, which may not have been previously included in the approach.

The disadvantages of the repair must be balanced against the complications associated with primary resection; for example, loss of olfaction from cribriform plate resection may be required regardless of closure technique.

At our institution, pedicle mucosal flaps are the first choice for use in the repair of large endoscopic transnasal craniotomies. We still use free grafts to close smaller defects, however. There is good evidence that small defects < 10 mm can be managed with free grafts, no lumbar drainage, and even in an outpatient surgery setting.[7] The decision to use pedicled flaps must be made at the beginning of the procedure; we use the following criteria as indications for using large pedicled mucosal flaps: the presence of a skull base defect > 1 cm, extensive disruption of the arachnoid layer, previous radiotherapy, and the use of any posterior fossa or transclival approach. These criteria are derived from our experience with endoscopic skull base closure rather than data presented in this study.

We do not routinely use postoperative lumbar drainage and this has also become common at other institutions with endoscopic experience.[5,7,11,13,21] We feel that normal CSF pressure benefits the repair, and its drainage is associated with unnecessary risk. The low CSF pressure created by lumbar drainage can result in separation of the initial subdural inlay graft from the dural edges. The use of lumbar drains requires skilled nursing staff and can result in complications at the local insertion site, meningitis, and theoretically, an increased risk of pneumocephalus from a decreased pressure gradient. Lumbar drains and CSF diversion are still used in a small group of patients with raised intracranial pressure, early postoperative leakage, or after radiation therapy. In patients with raised intracranial pressure, both lumbar drainage and possible permanent CSF diversion may be required.[6]

Conclusions

The use of large pedicled mucosal flaps is a major advance in endoscopic SBS. The ability to obtain wide surgical access to a pathology via an endoscopic transnasal craniotomy has allowed refinement in endoscopic surgical techniques. Better hemostasis, sharp extracapsular dissection, and genuine bimanual surgery are more easily performed with this method. The use of pedicled mucosal flaps requires careful preoperative evaluation of the reconstructive options available. Importantly, the size and location of the defect must be anticipated as the flaps are raised at the beginning of the procedure. Multilayered repair with these flaps provides a reliable reconstruction option for endoscopic surgeons when large defects in the ventral skull base are encountered.

Disclaimer

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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