Endoscopic Surgery for Pituitary Tumors

Joshua W. Lucas, MD*, Gabriel Zada, MD

KEYWORDS

• Endoscopy • Pituitary lesions • Transsphenoidal surgery

KEY POINTS

- Endoscopic transsphenoidal surgery has proven to have similar or better results compared with traditional microsurgical techniques, with equal or reduced complication rates.
- The endoscopic technique affords the surgeon improved visualization, illumination, and surgical mobility.
- The endoscopic approach to the sella turcica can be divided into a nasal stage, a sphenoid stage, a sellar stage, and a reconstruction stage.

INTRODUCTION

In the long history of the transsphenoidal approach to the sella turcica, the use of neuroendoscopy as the sole means of visualization and surgical resection of pituitary lesions is a relatively recent technique. Despite its relatively short existence, however, this technique has been extensively refined and has become commonplace in many operating rooms around the world.

The neuroendoscopic approach to pituitary lesions has been shown in numerous studies to have tumor resection and hormonal remission rates equal to or better than the classic microsurgical transsphenoidal technique. Furthermore, the rate of complications associated with neuroendoscopic procedures has been shown to be equal to if not less than those reported from series of microsurgical procedures. The use of the endoscope for transsphenoidal surgery has provided improvements in panoramic visualization, the ability to use angled lenses to look around anatomic “corners,” improved illumination, and has facilitated the development of extended approaches to the skull base. The future of neuroendoscopic resection of pituitary lesions lies in the continued miniaturization and innovation of endoscopic instrumentation, advances in optical technology, and improved visualization systems.[1]

The endonasal endoscopic transsphenoidal technique consists of four major stages: nasal, sphenoid, sellar stage, and reconstruction. In the nasal stage, the endoscope is advanced through the nasal cavity to identify the sphenoid ostium, followed by a posterior septectomy and anterior sphenoidotomy. The sphenoid stage is characterized by widening of the anterior sphenoidal exposure, removal of the sphenoid septa, and identification of key landmarks surrounding the sellar floor. The sellar stage involves removal of the bony sellar floor, dural opening, and surgical treatment of the pathologic lesion. Finally, in the reconstruction stage, prevention or repair of cerebrospinal fluid (CSF) leaks is addressed.

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Department of Neurosurgery, University of Southern California, 1200 North State Street, Suite 3300, Los Angeles, CA 90033, USA
* Corresponding author.
E-mail address: joshuawlucas@gmail.com

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HISTORY OF ENDOSCOPIC TRANSSPHENOIDAL SURGERY

The first documented transsphenoidal approach for resection of a pituitary lesion dates back to 1906 by Schloffer.[2,3] His efforts were soon followed by those of Kocher and von Eiselsberg in the early part of the twentieth century. Cushing introduced the sublabial transseptal technique in 1914, which reduced the degree of nasal trauma associated with earlier external rhinotomy incisions. The operative microscope, popularized by Hardy in the 1960s, revitalized the transsphenoidal procedure by providing the magnification and illumination that made precise tumor resection possible.[2]

Surgical endoscopy first emerged in the fields of otolaryngology, gastroenterology, and urology.[1,3] Early endoscopes were originally used only for visualization purposes. Endoscopic procedures, however, quickly became possible with the advent of specially designed endoscopic surgical instruments and electrocautery.[4] Walter Dandy was among the greatest pioneers of early neuroendoscopy, performing endoscopic intraventricular operations as early as 1920 and contributing greatly to the development of improved endoscopic instrumentation.[1]

The use of the endoscope in conjunction with the microsurgical approach to the sella was first proposed by Guiot and colleagues[3,5] in 1963, though he abandoned the procedure due to inadequate visualization. Apuzzo and colleagues[6] brought the procedure more recognition in 1977, reporting the use of angled (70°–120°) endoscopes to visualize the sellar contents following microsurgical dissection. In the 1990s, multidisciplinary teams of neurosurgeons and otolaryngologists developed "pure" endoscopic techniques without the use of an operating microscope for removal of sellar lesions. Jankowski and colleagues[7] published a report on their experience performing pure endoscopic transsphenoidal resections of pituitary adenomas in 1992. In 1996, Jho and Carrau[8,9] described their technique of a pure endoscopic approach in detail and, in 1997, published their report of endoscopic removal of pituitary adenomas in 44 patients. Cappabianca and colleagues[10] also helped to develop the pure endoscopic approach and introduced the concept of functional endoscopic pituitary surgery in 1998. The endoscopic approach to the sella continued to be refined during the early twenty-first century, and with technologic advancements such as neuronavigation and microvascular Doppler ultrasonography, neuroendoscopy has expanded to now include extended approaches to the skull base.[3,11] Current endoscopic endonasal approaches to the skull base can now provide access to a wide arc of pathologic conditions along the midline skull base, from the frontal sinuses to the level of the foramen magnum or even high cervical spine in selected cases (**Fig. 1**).

COMPARISON OF NEUROENDOSCOPY AND MICROSURGERY FOR PITUITARY LESIONS

Despite early skepticism regarding the application of endoscopic techniques to resection of sellar lesions, numerous studies have shown equivalent or improved rates of tumor excision and tumor remission with endoscopic approaches to pituitary lesions compared with microsurgical approaches.[12–14] It has been an ongoing challenge, however, to attempt to draw comparisons between comparable surgical approaches such as the microscopic and endoscopic transsphenoidal approaches, for several reasons. First, a lack of Class I evidence or prospective randomized studies exist in attempting to draw these conclusions. Second, many current endoscopic studies are compared with historical control series dating back several decades. As surgical technology (ie, endoscopic visualization) progresses, so do advances in neuroimaging, medical therapy, and radiosurgical options for treatment of many of the same lesions. Finally, a limited degree of selection bias exists that makes it difficult to know why certain patients underwent various procedures. Surgical series of the most experienced pituitary surgeons were primarily performed using the microscope until the last decade and these studies still define the gold standard for treatment of many of these lesions.[15]

Nevertheless, improved endocrinologic results in functioning adenoma resections have been reported using a pure endoscopic approach compared with the microsurgical technique.[16–19]

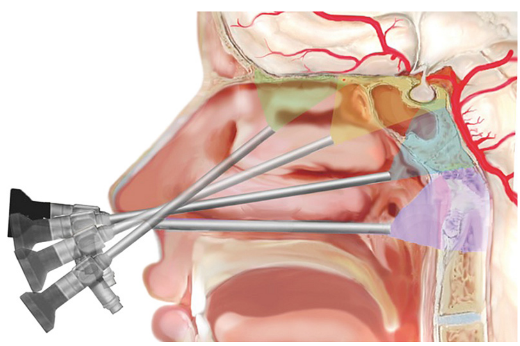

Fig. 1. Extended endoscopic approaches have been developed that allow access from the anterior skull base anteriorly to the clivus posteriorly. (*Courtesy of* Luigi Cavallo, MD, PhD.)

A meta-analysis done by Tabaee and colleagues[20] compiled data on 821 patients with pituitary adenomas treated with endoscopic pituitary surgery and found a gross tumor resection rate of 78%. The study also reported hormonal remission following endoscopic tumor resection in 81% of corticotropin-secreting tumors, 84% of growth hormone (GH)–secreting tumors, and 82% of prolactin-secreting tumors, which are equivalent to or better than rates reported in similar meta-analyses of microsurgical approaches. Another recent meta-analysis by Doward[21] included 12 additional studies and the original studies used in Tabaee's meta-analysis to assess endocrinologic outcomes after resection of functioning tumors. The overall rate of complete tumor resection associated with endoscopic resection of pituitary adenomas was 72%. Remission rates were higher for microadenomas (84% remission) than macroadenomas (69% remission) or invasive tumors (40% remission). This study also compared endocrinologic remission rates. The data showed slightly higher rates of hormonal remission associated with endoscopic procedures for functional microadenomas, as compared with microsurgical resection (84% vs 77%). For macroadenomas, the difference was more profound, with 70% remission in endoscopic procedures versus 45% remission in microsurgical procedures. It has been suggested that rates of remission in microadenoma resections, when compared with macroadenoma resections, performed via a pure endoscopic technique, would not be different from that performed with microsurgery because the expanded view gained with the endoscope does not offer a significant advantage over the standard microscopic view.[16]

In addition to similar or improved efficacy rates, endoscopic techniques may offer some distinct technical advantages over microsurgical techniques. Well-recognized drawbacks of the microsurgical approach include a narrower surgical field that is limited by the width of the nasal speculum, reduced illumination near the surgical target, the inability to visualize specific anatomic landmarks such as the carotid protuberances that define the limits of the sella, and an operative view that is limited by line of sight, making it challenging to fully inspect the resection cavity.[2,22] Pure endoscopic techniques allow improved panoramic visualization and illumination, obviating a nasal speculum. Also, the use of angled endoscopes essentially creates a surgical field limited only by the extent of dissection and available instrumentation. From this widened surgical field, modified endoscopic transsphenoidal procedures have been developed to access lesions arising or extending outside of the sella, including cavernous sinus, suprasellar, planum sphenoidale and/or olfactory groove, and retroclival lesions in which prior exposure via a microsurgical transsphenoidal approach was accompanied by formidable challenges.[23] Another advantage of the endoscopic technique includes minimal nasal mucosal trauma, thereby essentially obviating nasal packing unless a significant CSF leak or mucosal bleeding is observed intraoperatively, and reducing patient discomfort postoperatively.[2,24] Furthermore, once a surgeon overcomes the initially steep learning curve associated with endoscopic techniques for transsphenoidal surgery, a potential decrease in blood loss, operating time, and overall length of hospital stay may be appreciated.[12,25,26]

Potential disadvantages associated with the endoscopic technique include a loss of binocular three-dimensional (D) vision, a steep initial learning curve, and potential injury to the nasal mucosa that is not under direct visualization on insertion or withdrawal of instruments from the surgical field.[15] Endoscopic techniques are, by necessity, limited by the projection of a 3D image onto a 2D screen, whereas 3D visualization is readily available with the operating microscope. This shortcoming can be partially corrected by the use of large (>50 cm) high-definition video screens and tactile or haptic feedback to help the surgeon gauge surgical depth.[27] Also, the use of a two-surgeon, three-handed technique that allows dynamic movement of the endoscope and comparison between that movement and the motion of the surgical instruments can partially help offset the loss of depth perception.[11] Newer three-dimensional visualization systems are rapidly improving and may, one day, all but obviate this shortcoming associated with endoscopic surgery.[20] The learning curve for neuroendoscopy was initially thought to be prohibitively steep for the procedure to gain widespread acceptance, but recent publications of transitions from microsurgery to endoscopy within large teaching hospitals have reported that the learning curve may not be as steep as originally thought.[27] Also, the endoscopic technique is being introduced widely in residency training programs and more young neurosurgeons are becoming familiar with the endoscopic equipment and instrumentation. Most practicing neurosurgeons, however, were trained with the microsurgical technique and general familiarity with the operating microscope continues to be much greater than that for the endoscope. Finally, compared with endoscopic techniques, the use of a nasal speculum with microsurgery helps to protect the nasal mucosa from injury caused by insertion and withdrawal of instruments.[2] Increased care must be taken by the endoscopic neurosurgeon to recognize that the nasal mucosa not under visualization is subject to injury and must take measures to prevent this.

EQUIPMENT AND SURGICAL INSTRUMENTATION

The continued development and refinement of endoscopic equipment and surgical instrumentation specifically designed for use with neuroendoscopy has greatly contributed to its advancement as a viable procedure for transsphenoidal approaches to the sella and other nearby skull base regions. Basic components of the endoscopic set-up include the rigid-lens endoscope itself, a camera, a fiberoptic cable to connect the endoscope with the monitors, a light source, a large high-definition video monitor, and a video recording system.[22] The most commonly used endoscope is 4 mm in diameter with a length of 18 or 30 cm (**Fig. 2**). Variations in lens angulation are available for specific steps of the operation, including a 0-degree scope, a 30-degree scope, and a 45-degree scope. Larger-angle scopes ranging between 70- to 120-degrees are available for extended approaches, although they are rarely required for most endoscopic skull base operations.

In general, endoscopic instruments are long, rotating tools with a single straight shaft that are equipped with angled tips.[28] The angled tips on the working ends of many surgical instruments permit a wider range of motion than standard instruments. Compared with the microsurgical technique, in which bayoneted instruments are typically used to avoid interference with the light source, the use of straight instruments is preferred with endoscopy. The endoscope is introduced into the nostrils along with a sheath, which is connected to an irrigation system that allows cleaning of the lens without repeated removal and reentry of the telescope. A three-charge-coupled digital video camera paired with a high definition monitor is used to provide an optimized view of the surgical field. An endoscope holder may be used during the sellar phase of the procedure to stabilize the view of the surgical field, but its use negates the dynamic movement that helps to compensate for loss of depth perception.[11] The use of neuronavigation systems, although not required, can occasionally be helpful in patients with recurrent lesions or abnormal sellar or paranasal sinus anatomy.

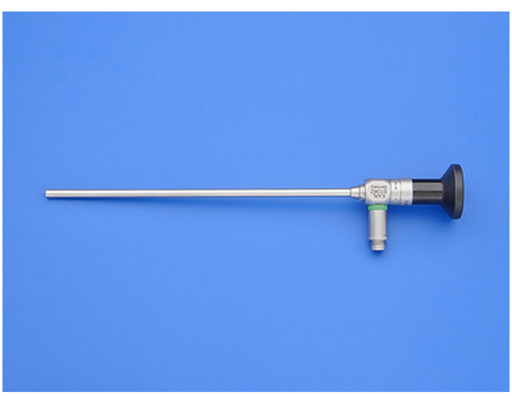

Fig. 2. The modern endoscope used for endoscopic transsphenoidal neurosurgery. (*Courtesy of* Karl Storz, Inc., Tuttlingen, Germany.)

PREOPERATIVE ASSESSMENT

A thorough clinical evaluation is necessary for all patients before any operative intervention. In patients with pituitary tumors, this includes formal visual field examination by an ophthalmologist, evaluation for prior endonasal surgery, and a thorough endocrinologic evaluation. A full endocrinologic evaluation for pituitary lesions includes serum levels of thyrotropin, free thyroxine, GH, insulinlike growth factor-1, corticotropin, prolactin, cortisol, luteinizing hormone, follicle-stimulating hormone (in women), and free testosterone (in men). Endocrine dysfunction, especially pertaining to the cortisol and thyroid axes, should be corrected before operative intervention.

Preoperative imaging is imperative for assessing the relevant anatomy that will be encountered during the approach. MRI of the head with and without gadolinium contrast and CT imaging of the head will show the degree of pneumatization of the sphenoid sinuses and the anatomy of the sphenoid septa. Identification of the target lesion, normal pituitary gland, stalk, optic chiasm and optic nerves, and course of the internal carotid arteries should also be assessed, often relying on sagittal and coronal images as the most useful planes to assess relevant neuroanatomic relationships.

The anatomy of the sella turcica, sphenoid sinus, and adjacent anterior and central skull base structures is highly variable. Preoperative imaging, specifically midsagittal MRIs with contrast, must be assessed to identify the morphology of the sellar floor and the configuration of septa within the sphenoid sinus (**Fig. 3**). The sellar angle, defined as the angle between lines drawn tangential to the sellar floor originating at the tuberculum sellae point and the sellar-clival point, can be used to classify the different sellar floor morphologies (**Fig. 4**). Prominent sellar floors (sellar angle $<90^{\circ}$) and curved sellar floors (sellar angle between 90° and 150°) can usually be easily located using defined anatomic landmarks intraoperatively. Flat sellar floors (sellar angle $>150^{\circ}$) or conchal (no sellar floor) sphenoid phenotypes occur in 11% and 1% of patients,

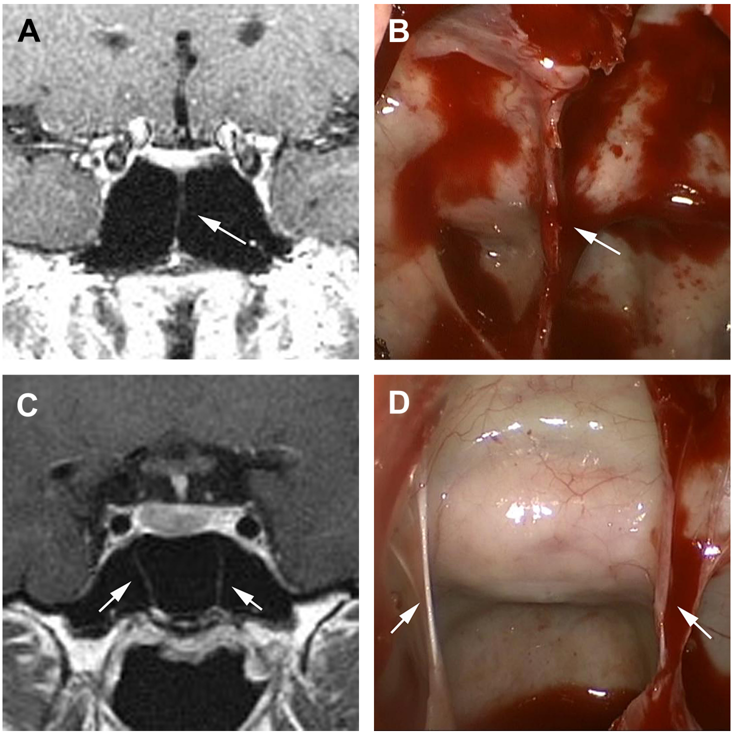

Fig. 3. Correlation of coronal MRI and intraoperative endoscopic views of vertical sphenoid septa in patients with simple sphenoid sinus morphology. The presence of one midline septa (*A* and *B*, *white arrows*) can be used to identify the anatomic midline. The presence of two symmetric septa (*C* and *D*, *white arrows*) can be used to approximate the lateral boundaries of the sella. (*From* Zada G, Agarwalla PK, Mukundan S, et al. The neurosurgical anatomy of the sphenoid sinus and sellar floor in endoscopic transsphenoidal surgery. J Neurosurg 2011;114(5):1319–30; with permission.)

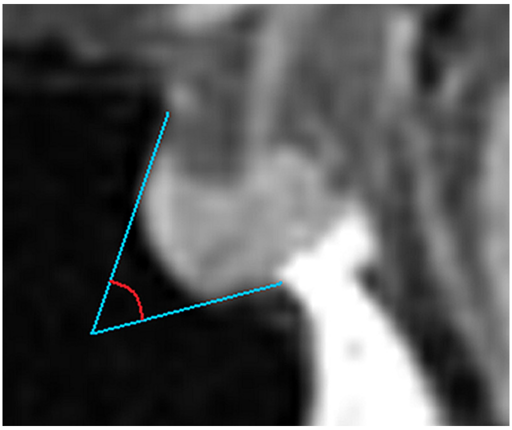

Fig. 4. The sellar angle, defined as the angle formed from lines drawn tangentially to the sella originating at the tuberculum sellae and the sellar-clival junction. (*From* Zada G, Agarwalla PK, Mukundan S, et al. The neurosurgical anatomy of the sphenoid sinus and sellar floor in endoscopic transsphenoidal surgery. J Neurosurg 2011;114(5):1319–30; with permission.)

respectively, and have been shown to be more difficult to identify intraoperatively; neuronavigation systems should, therefore, be strongly considered in these patients (**Figs. 5** and **6**). Additionally, neuronavigation systems are recommended for patients who exhibit complex sphenoid sinus configurations (29% of patients), consisting of two asymmetric septa, three or more septa, or horizontal septa, and patients who have undergone previous transsphenoidal surgery.[29]

SURGICAL TECHNIQUE

The endoscopic transsphenoidal approach to pituitary lesions has been continuously refined since it was first described.[2,22,28,30] Variations to the procedure exist, yet the following represents a general description and the authors' preferred surgical technique used for this approach.

Preparation and Positioning

The video monitor is positioned behind the patient's head and in direct line of sight of the surgeon who, in most cases, stands on the

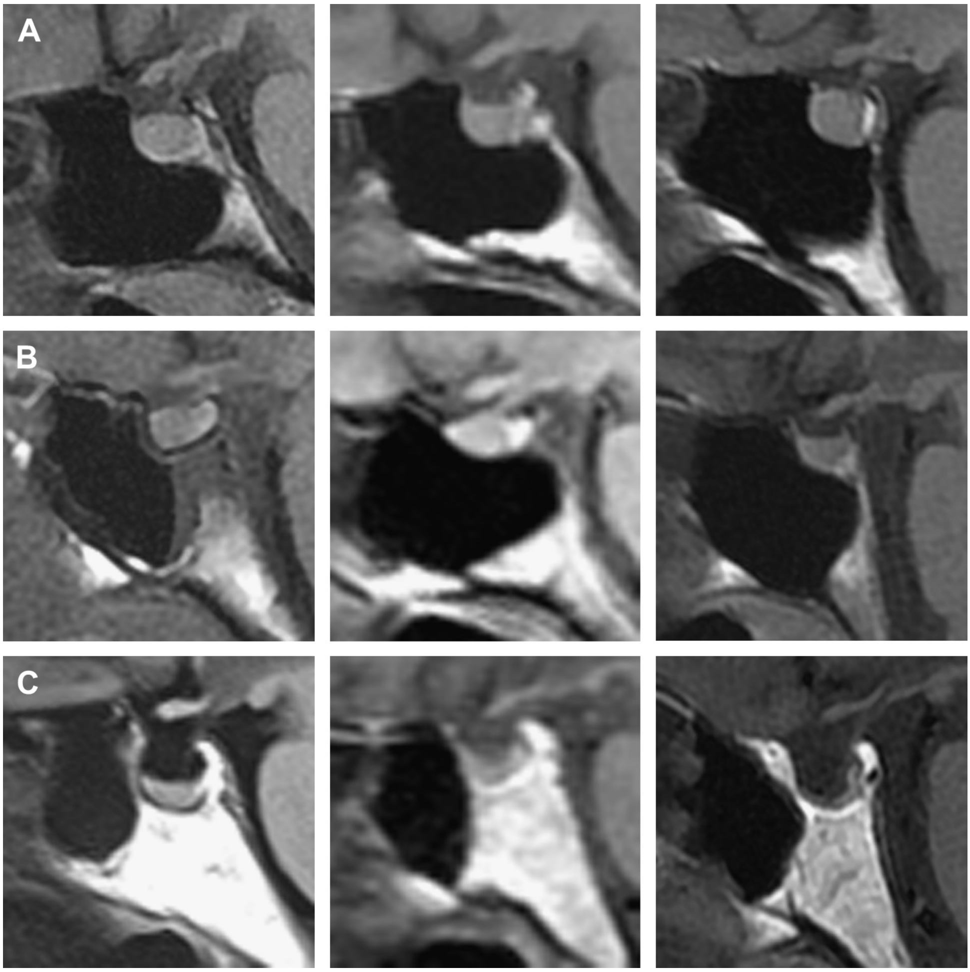

Fig. 5. Variations in sellar phenotypes on MRI. (*A*) Prominent sellar floor. (*B*) Curved sellar floor. (*C*) Flat sellar floor or conchal sphenoid phenotype. (*From* Zada G, Agarwalla PK, Mukundan S, et al. The neurosurgical anatomy of the sphenoid sinus and sellar floor in endoscopic transsphenoidal surgery. J Neurosurg 2011;114(5):1319–30; with permission.)

patient's right side. The anesthesiologist is positioned on the patient's left side. The bed is turned approximately 160° away from the anesthesiologist and the patient is placed in a semirecumbent position with the thorax elevated to 15° to promote venous outflow. If neuronavigation is to be used, the head is placed in rigid three-point fixation. The head is positioned with a slight degree of rotation, approximately 10° toward the surgeon, with the midline of the patient's head parallel to the lateral walls of the operating room and the bridge of the nose parallel to the floor. The degree of flexion and/or extension of the patient's head depends on the location of the lesion. Lesions located primarily in the clivus or sphenoid sinus require slight flexion of the head to permit working space for the endoscope. Lesions located more anteriorly, such as those based in the planum sphenoidale, require the head to be in a neutral or slightly hyperextended position. As with any operation, all endoscopic equipment and instrumentation should be checked before the operation to ensure proper function. The surgeon must communicate with the anesthesia team before the operation to discuss medication administration, especially with regard to hormone replacement and antibiotics. The authors prefer to use intravenous cefazolin for routine cases.

After intubation, the endotracheal tube and an orogastric tube are positioned to the left side of the patient's mouth. All lines and monitoring devices are similarly positioned to the patient's left side. These maneuvers free the patient's right side for the surgeon. The nasal cavity is then prepared by administration of the nasal decongestant oxymetazoline, followed by intranasal cleansing with an aqueous antiseptic such as chloroxylenol *United States Pharmacopeia* 3%

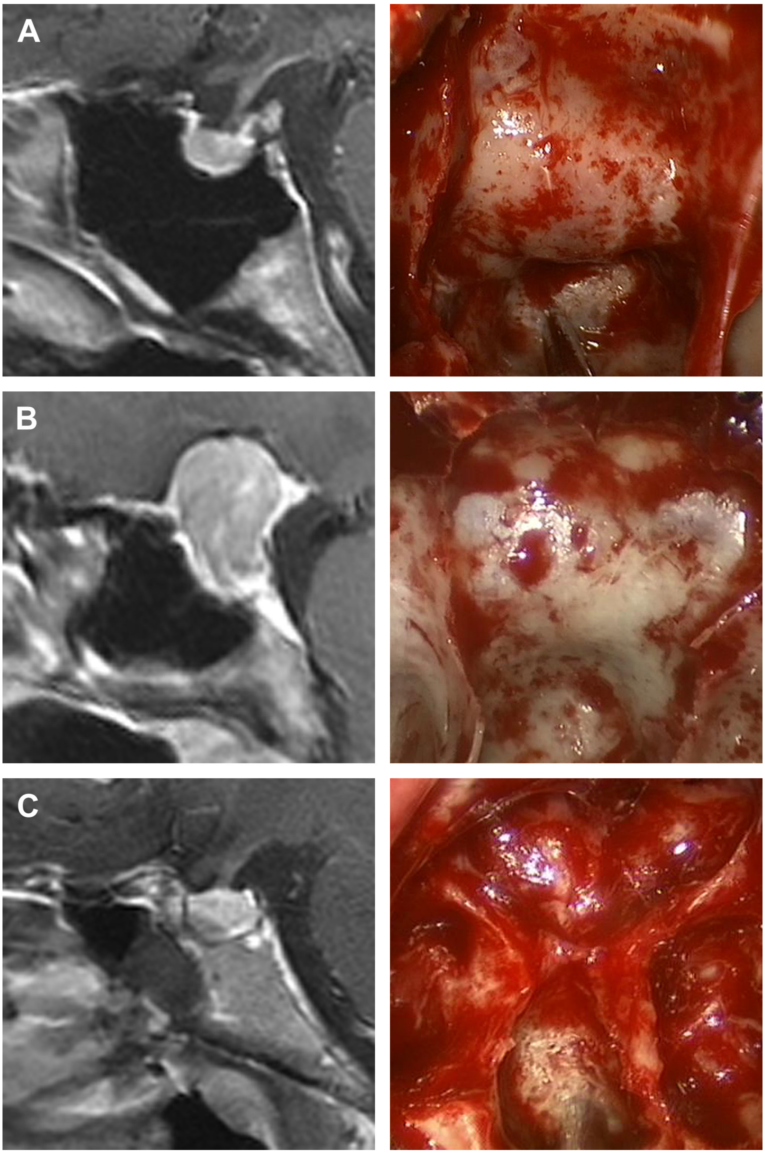

Fig. 6. Sagittal MRI and corresponding intraoperative endoscopic images of the sellar floor. (*A*) Prominent sella phenotype that is easily identifiable intraoperatively. (*B*) Curved sella phenotype. (*C*) Flat sella phenotype that is very difficult to differentiate from the clivus, making neuronavigation extremely important. (*From* Zada G, Agarwalla PK, Mukundan S, et al. The neurosurgical anatomy of the sphenoid sinus and sellar floor in endoscopic transsphenoidal surgery. J Neurosurg 2011;114(5):1319–30; with permission.)

(Techni-Care Solution) or iodine solution. Finally, the nasal region is prepped externally and draped with towels. The abdomen is also prepared under sterile conditions in the event that fat graft harvesting is required during the reconstruction phase. For larger lesions with a high likelihood of intraoperative CSF leakage, a small right-lower-quadrant incision is used so that abdominal fascia can be harvested if necessary. For smaller leaks, or if abdominal cosmesis is an issue, a small (2 cm) subumbilical curvilinear incision is planned.

Nasal Stage

The nasal stage of the operation begins with the surgeon using a short (18 cm) 0° endoscope. The endoscope can be introduced via either nostril, although the right side is used more frequently. On introduction of the endoscope, the landmarks that should be initially identified in the nasal cavity are the inferior turbinate (laterally), the nasal septum (medially), and the choana (posteriorly) (**Fig. 7**A). The surgeon should assess for evidence of prior surgery or any other anatomic variations,

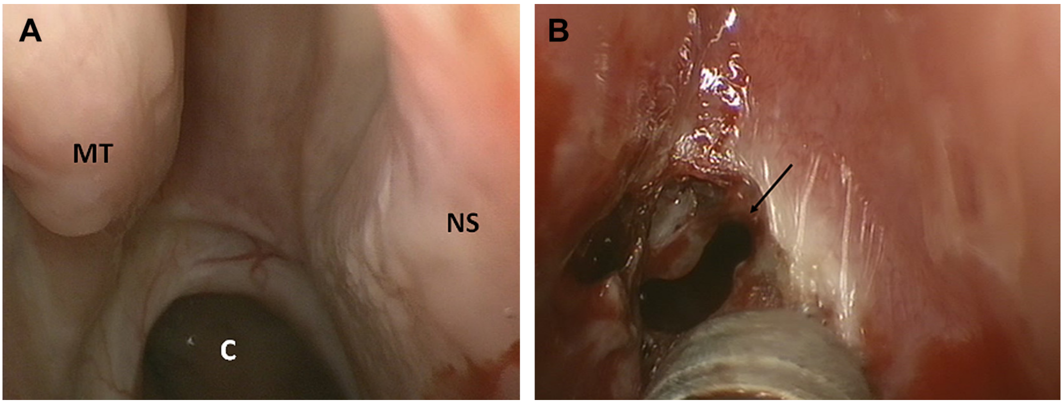

Fig. 7. The nasal stage. (*A*) On entering the nares, the choana (C) is immediately visualized, with the middle turbinate (MT) identified laterally and the nasal septum (NS) medially. (*B*) The sphenoid ostium (*black arrow*) is identified and coagulated in preparation for gaining access to the sphenoid sinus.

including a deviated septum or septal perforation, septal spurs, polyps, or synechiae. Once the choana is identified, maneuvering the endoscope superiorly allows identification of the middle turbinate, which arises from the region of the ethmoid sinuses superiorly. A Freer instrument is used to gently displace the middle turbinate laterally, attempting to preserve the integrity of the overlying mucosa and minimize bleeding at all times. Intermittent packing with lidocaine and/or epinephrine pledgets placed between the middle turbinate and nasal septum helps to maintain the developed working space between the middle turbinate and nasal septum and achieve hemostasis. Following sufficient lateral displacement of the middle turbinate, the endoscope is advanced and angled slightly superiorly, to identify the superior turbinate posteriorly. In rare cases, resection of the middle turbinate will be required to widen the surgical corridor, and is typically reserved for extended skull base operations or patients with acromegaly and enlarged turbinates.

The next landmark that should be identified is the sphenoid ostium, which is usually located just medial to the inferior aspect of the superior turbinate, approximately 1.5 cm superior to the superior edge of the choana. The sphenoid ostium is occasionally concealed by mucosa or a thin layer of bone, in which case attempting to first identify the ostium on the other side may be of benefit. Use of neuronavigation is also helpful in confirming the trajectory into the sphenoid sinus, after which a small dissector instrument, such as a Freer or a fine suction cannula, can be used to probe gently for the ostium and enter the sinus. Once the ostium is identified, its mucosal edges are coagulated using mild monopolar cautery, which can be extended down the medial and inferior surface of the sphenoid rostrum (see **Fig. 7**B). Avoidance of inferolateral cauterization and dissection helps to prevent arterial bleeding from septal braches of the sphenopalatine artery.

Local anesthesia (lidocaine 1% with epinephrine 1:100,000) is then injected medially into the posterior nasal septum using a spinal needle with the tip bent to 20°. An anterior sphenoidotomy is initialized by using a mushroom (Stammberger) punch to widen the aperture of the sphenoid ostium. The preferred direction of removal of the sphenoid rostrum is in a direction inferior and medial from the ostium. This maneuver is almost always performed on both sides of the nasal cavity, although the approach may be performed entirely from one side, depending on the size and location of the target lesion, and the requirement for using instruments through both nostrils.

A Cottle elevator is used to create a curvilinear incision in the posterior septum immediately over the keel of the sphenoid rostrum (vomer and perpendicular plate of the ethmoid). The Cottle elevator or a suction instrument (ie, suction-Freer) is used to strip the nasal mucosa along a subperiosteal plane on both sides of the vomer, creating two mucosal flaps and exposing the entire bony sphenoid rostrum. Once adequate exposure of the bony keel is achieved, it can be removed using a stout pituitary or Jansen-Middleton rongeur (**Fig. 8**). The remaining superior-most and inferior-most aspects of the bony keel of the vomer serve as useful midline markers during the remainder of the operation (**Fig. 9**). Soft tissue from the posterior septum and elevated superior mucosal flaps can be removed using a sinus microdebrider or Blakesley forceps, ensuring not to resect tissue in the inferolateral aspect of the exposure where the sphenopalatine artery enters the nasal cavity. Arterial bleeding encountered from the sphenopalatine

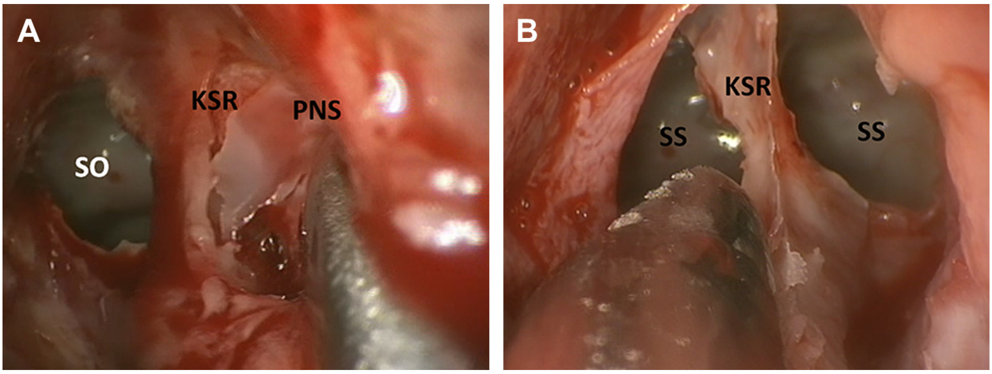

Fig. 8. The nasal stage. (*A*) A posterior septectomy is performed through the posterior nasal septum (PNS) after enlarging the sphenoid ostium (SO). The keel of the sphenoid rostrum (KSR) is identified. (*B*) Removal of the posterior nasal septum allows bimanual access to the sphenoid sinus (SS).

artery at this point requires cauterization or even clipping of the artery and increases the risk for delayed arterial epistaxis despite initial hemostasis. A backbiter instrument may be used to extend the posterior septectomy more anteriorly as required to improve communication between both sides of the nasal cavity. The lateral and superior soft tissue and bony overhang of the sphenoid rostrum and sinus are resected using a Kerrison rongeur, microdebrider, or Blakesley forceps to provide adequate room to dock the endoscope superolaterally for the next stage of the procedure. The bony rostrum is typically removed down to the level of the floor of the sphenoid sinus using a downbiting Kerrison rongeur or high-speed drill, to maximize working space for the endoscope and two instruments (**Fig. 10**). Care should be taken to remove the sphenoid rostrum in pieces and not en bloc because removal of large fragments can cause lacerations to the nasal mucosa.

Sphenoid Stage

On entering the sphenoid sinus, the initial goal is to identify key anatomic landmarks and correlate them with the neuroimaging findings. The surgeon must always study the anatomy of the sphenoid sinus on preoperative imaging, including the morphology and curvature of the sellar floor, the location and course of the carotid arteries, and the configuration of any sphenoid septations that may be present. Septations within the sphenoid sinus should be correlated with the MRI and CT, and often lead directly to the carotid arteries laterally and posteriorly. Careful removal of these septations is performed using a pituitary forceps or Kerrison rongeur. A dehiscent bony covering of the internal carotid artery is identified in up to 10% of the population. The sphenoid mucosa can be stripped and removed using suction and a small-cup forceps.

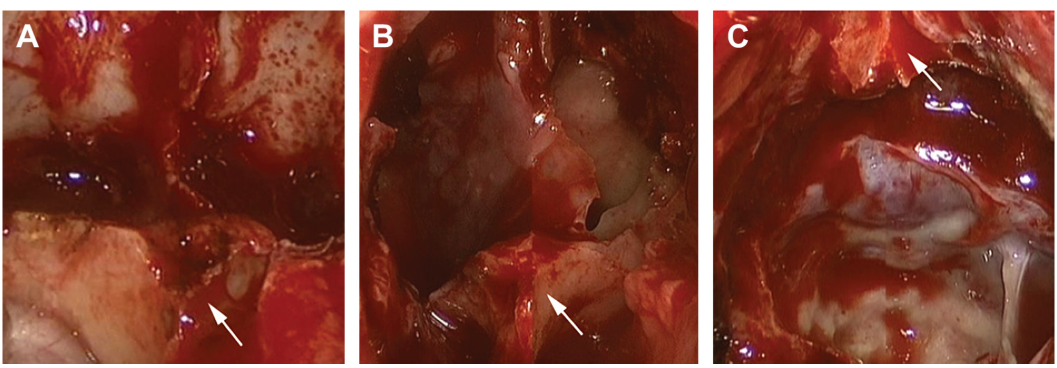

Fig. 9. The nasal stage. Intraoperative endoscopic images of relatively constant midline markers that can often be used even in the presence of complex sphenoid sinus configurations. These markers include the base of the vomer (*A* and *B*, *white arrows*) and the superior rostrum of the sphenoid (*C*, *white arrows*). (*From* Zada G, Agarwalla PK, Mukundan S, et al. The neurosurgical anatomy of the sphenoid sinus and sellar floor in endoscopic transsphenoidal surgery. J Neurosurg 2011;114(5):1319–30; with permission.)

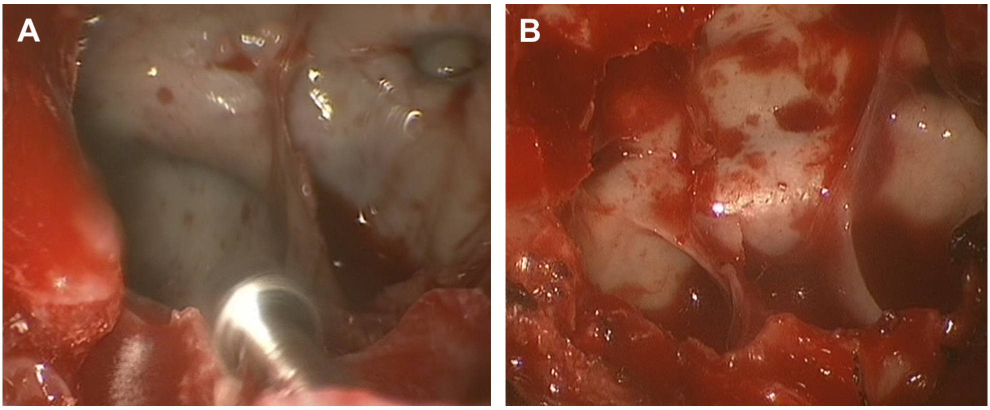

Fig. 10. The nasal stage. (*A*) The bony rostrum is removed to the level of the floor of the sphenoid sinus using a high-speed drill. (*B*) The endoscope and instruments are subsequently advanced through the aperture into the sphenoid sinus.

Once the posterior wall of the sinus is visible, the surgeon should identify the sellar floor, with the tuberculum sphenoidale and planum sphenoidale located above and the clivus located below (**Fig. 11**). Lateral to the sellar floor, the surgeon should identify the bony prominences of the cavernous carotid arteries and the optic nerves, with the opticocarotid recesses between them. The floor of the sella turcica is prominent and thus easily recognizable in most patients; however, a flat, less prominent variety exists in approximately 10% of people.[29] Although neuronavigation is not required for the procedure, it can be extremely beneficial to confirm the identification of key anatomic landmarks in patients with flat sellar subtypes and presellar (conchal) sphenoid sinuses, and in patients with previous transsphenoidal surgery. Finally, thorough saline irrigation of the sinus using a large bulb syringe is performed to remove blood and bone fragments in preparation for entering the sella.

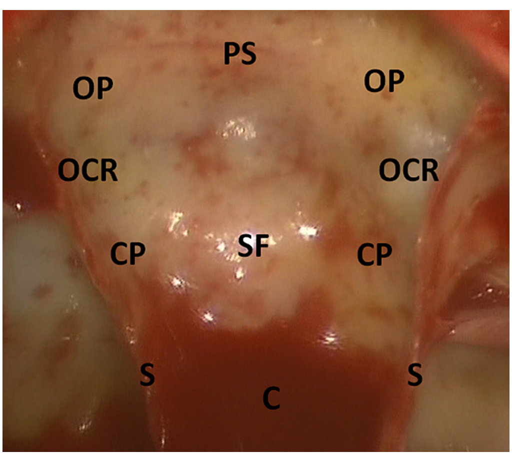

Fig. 11. The sphenoid stage. Anatomic landmarks surrounding the sellar floor (SF) are identified. Paired sphenoid septa (S) can be used as lateral guidelines for dissection if confirmed on preoperative MRI. C, clivus; CP, carotid protuberance; OCR, opticocarotid recess; OP, optic protuberance; PS, planum sphenoidale.

Sellar Stage

For the sellar phase, the long (30 cm) 0-degree endoscope is used and the operation is converted to a two-surgeon, three-handed technique, so that bimanual microdissection can be performed. Alternatively, the endoscope is fixed with an endoscope holder to permit a single surgeon to work with both hands, although this is not the authors' preference. The floor of the sella, when expanded and thinned by an intrasellar lesion, can usually be fractured open using a pituitary rongeur or blunt nerve hook (**Fig. 12**). In some cases, a thicker

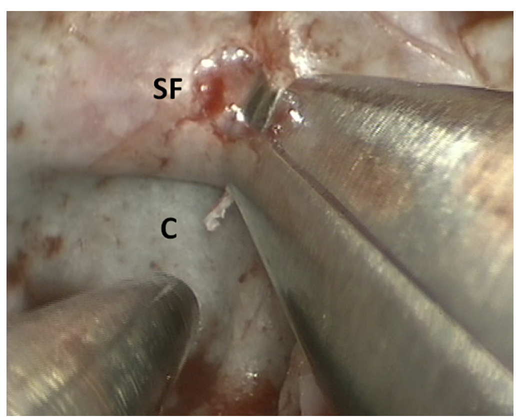

Fig. 12. The sellar stage. When sufficiently thinned by an intrasellar lesion, the sellar floor (SF) can be easily fractured with a pituitary forceps and then removed with a Kerrison rongeur. The clivus (C) aids in localizing the sellar floor.

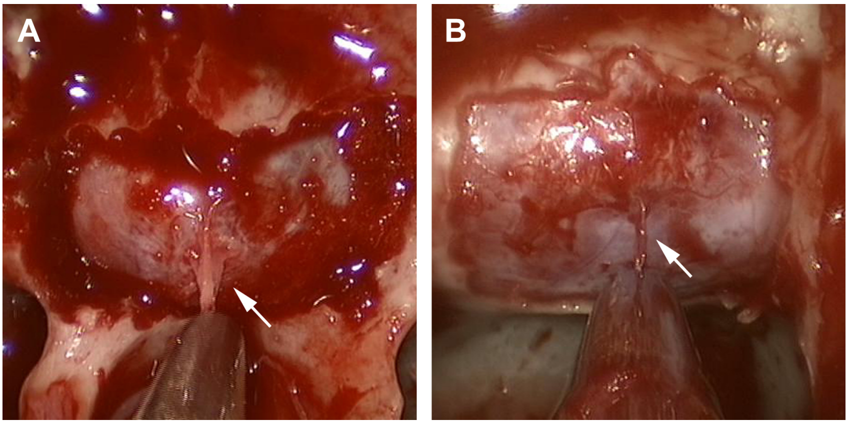

Fig. 13. The sellar stage. Intraoperative endoscopic images following removal of the bony sellar floor. A midline dural filum (*A* and *B*, *white arrows*) can be identified in approximately 50% of patients. (*From* Zada G, Agarwalla PK, Mukundan S, et al. The neurosurgical anatomy of the sphenoid sinus and sellar floor in endoscopic transsphenoidal surgery. J Neurosurg 2011;114(5):1319–30; with permission.)

sellar floor precludes this maneuver, requiring the use of a chisel or drill. A wide sellar exposure is performed, typically from one cavernous sinus to the other, using a 1 or 2 mm Kerrison rongeur (**Fig. 13**). In addition to seeing the cavernous sinuses laterally, the anterior intercavernous sinus is frequently identified in the rostral aspect of the exposure. The preoperative MRI is reviewed at this point to reassess the proximity and location of the internal carotid arteries. A micro-Doppler probe can be used to identify the internal carotid arteries and confirm the location of the planned dural opening. If there is any suspicion of a cystic lesion being an intrasellar aneurysm, a long 25-gauge spinal needle may be inserted through the dura into the sellar midline and aspirated to check for arterial blood. Once this has been ruled out, the dura is incised using a retractable microblade, ensuring penetration of both of its layers (**Fig. 14**). Dural opening is typically performed in a cruciate or x-shaped fashion; however, in cases where a dural specimen is desired for a pathological testing, a rectangular dural "window" can be resected. Following dural opening, a blunt nerve hook or microdissector is used to develop a subdural, extraglandular, or extracapsular plane around the circumference of the dural opening.

Following exposure of the gland and/or tumor, the target lesion is identified and removed using two-handed microdissection techniques. The surgeon should maintain constant awareness of the normal anterior and posterior pituitary gland, and attempt to identify and preserve them as much as possible. For microadenomas and small intrasellar macroadenomas, angled curettes and Hardy microdissectors are typically used to develop an extracapsular plane around the tumor before delivering it. For larger tumors, angled curettes and small-cup forceps can be used to loosen and deliver the tumor, first inferiorly along the floor of the sella, then laterally to the cavernous sinus on each side, and finally in a superior direction (**Fig. 15**A, B). Removing the

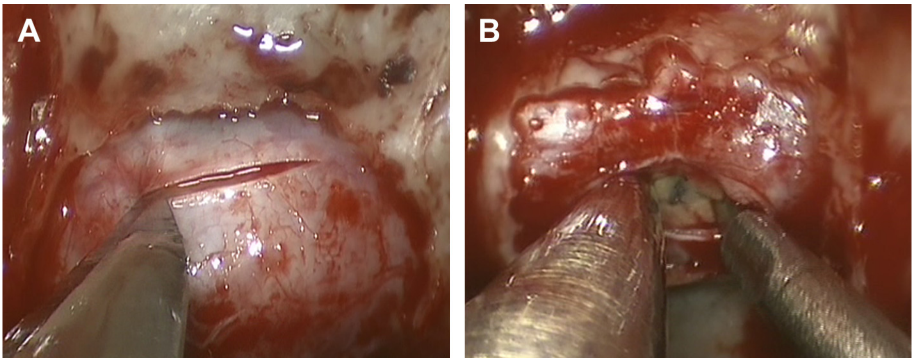

Fig. 14. The sellar stage. Various methods of dural opening. (*A*) A horizontal superior incision is made to create a dural "window" to send dural specimen for pathologic testing to inspect for evidence of dural invasion. (*B*) An x-shaped incision is used to maximize exposure to the gland and tumor.

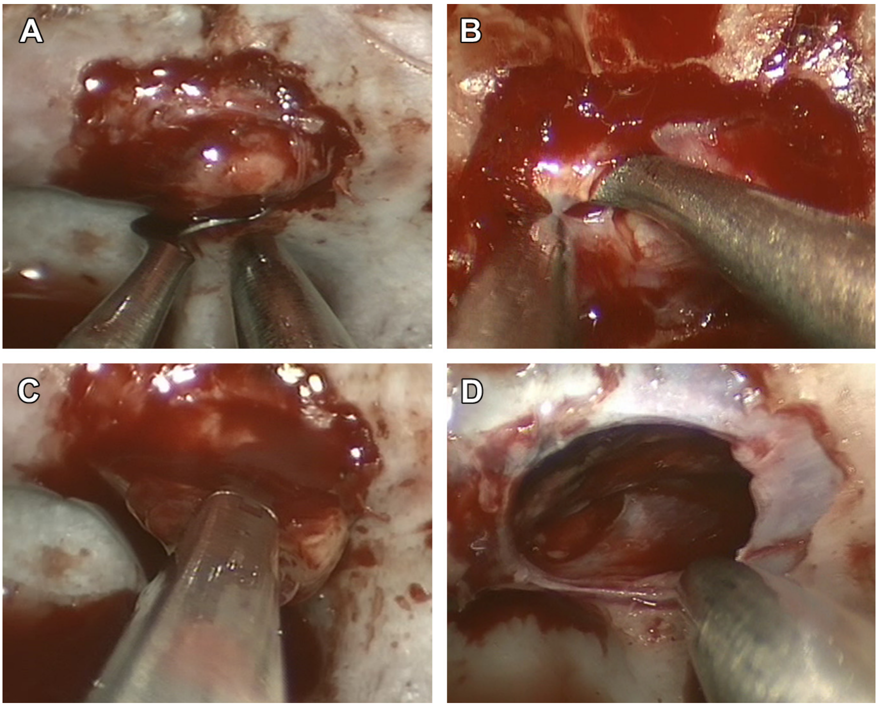

Fig. 15. The sellar stage. (*A* and *B*) An extracapsular plane is created by first dissecting inferiorly and then laterally to aid with tumor delivery. (*C*) Small-cup forceps are then used to remove the lesion. (*D*) The sella is examined for residual tumor before closure.

superior portion of the macroadenoma before the lateral and inferior portions can cause redundant prolapse of the diaphragma sella and arachnoid into the surgical field, obscuring visualization for subsequent tumor resection. Care should be taken to remove as much tumor as possible using a small-cup forceps, and sent for pathologic and/or tissue bank studies (see **Fig. 15**C). Once enough specimen has been collected, curettes and suction can be used to remove the remainder of the tumor (see **Fig. 15**D). The arachnoid may descend into the field of view at this point and should be manipulated carefully and protected with a cottonoid, thereby avoiding direct suctioning on the arachnoid to prevent CSF leakage. Cavernous sinus bleeding is frequently encountered following tumor removal and can be controlled in most settings using temporary gelatin foam packing of the sella and gentle pressure with a cottonoid. A 30° or 45° endoscope can be inserted to look laterally into the cavernous sinuses and superiorly to assess for residual tumor. In cases of macroadenomas with extensive suprasellar extension, the tumor will often descend spontaneously given enough time and gentle curettage. In patients with tumors that have a more firm consistency, a brief Valsalva maneuver, or insertion of saline into a lumbar drain, can be performed to assist with delivery of the tumor. Intrasellar and cavernous sinus hemostasis can typically be achieved using temporary packing with gelatin sponge, followed by lining the tumor cavity with oxidized cellulose (Surgicel).

Reconstruction and Closure

Once tumor resection is completed, the goal of reconstructing the skull base defect begins. Multiple methods of achieving reconstruction exist, including conventional reconstruction with autologous or artificial grafts, formation and rotation of a vascularized nasoseptal flap, and multilayered closure techniques using dural and bony substitute.[28,31]

The first goal of reconstruction is to assess for a spinal fluid leak, if not already evident. Asking the anesthesiologist to perform a Valsalva maneuver can also be helpful in identifying a subtle CSF leak. In simpler cases where no intraoperative CSF leak is identified, the tumor cavity is lined with cellulose (Surgicel), and additional pieces are used as a dural inlay and onlay. Insertion of a rigid buttress is avoided if no intraoperative CSF leak is observed. If an intraoperative leak is identified, an abdominal fat graft is typically harvested, although for smaller, weeping CSF leaks an allograft or dural substitute in combination with fibrin glue may be sufficient. In extended transsphenoidal cases, fascia lata from the thigh may be harvested, and a pedicled nasoseptal flap may be rotated ahead of time if a large CSF leak is anticipated. Following packing of the sella using any combination of gelatin foam, fat, or fascia lata, an absorbable plate may be tailored for larger sellar defects and inserted as an epidural inlay underneath the lateral edges of the bony sellar face to provide buttressing of the underlying grafts (**Fig. 16**).

Gentle irrigation and hemostasis is then performed. Sphenoid sinus and nasal hemostasis is typically achieved using cautery and absorbable cellulose and/or gelatin sponge. The mucosal margins surrounding the sphenoid rostrum, especially in the location of the sphenopalatine artery, are inspected for any bleeding and appropriately cauterized, preferably with bipolar cautery. The nasal septum is also inspected for any bleeding. The turbinates are medialized to reapproximate their natural position. Nasal packing is not routinely used but may be placed if bleeding persists. The choanae and oropharynx are carefully suctioned.

COMPLICATIONS

Despite the minimally invasive nature of transsphenoidal approaches to the sella turcica, complications can and do arise. Potential complications may occur during any stage of the procedure and can be classified according to where they occur.[32] Complications encountered within the nasal cavity during the approach include saddle nose deformity, anosmia, orbital fracture, cribriform plate injury with subsequent CSF leak, and hemorrhage from the sphenopalatine artery or its branches. Complications arising within the sphenoid sinus include sinusitis, mucoceles, and optic nerve or carotid artery injury from fracture of the sphenoid body. Potential complications associated with tumor resection and the sellar phase include CSF leak, hypopituitarism, diabetes insipidus, meningitis, postoperative hematoma, carotid artery or other vascular injury, optic nerve injury, ophthalmoplegia, subarachnoid hemorrhage, vasospasm, and tension pneumocephalus.

For both microscopic and endoscopic transsphenoidal surgery, the most common complications are CSF leak, meningitis, and sinusitis.[20,32,33] Recent studies have shown endoscopic techniques to be associated with similar or reduced rates of complications compared with microsurgical techniques.[20,25,32–34] Ciric and colleagues[35] published a widely renowned analysis in 1997 describing the observed rates of complications from microscopic transsphenoidal surgery. In 2002, Cappabianca and colleagues[32] published a large series of pure endoscopic techniques that analyzed the complication rates observed in these procedures and compared them to the complication rates of microsurgical procedures observed in Ciric's study. They found an overall decreased incidence of complications with the endoscopic technique. A recent systematic review performed by Tabaee and colleagues[20] analyzed nine studies with 821 total patients treated with endoscopic transsphenoidal surgery. They found pooled complication rates equal to or less than complication rates for microsurgical techniques reported in the literature. Another recent analysis by Berker and colleagues[33] of 624 endoscopic procedures for pituitary adenomas showed rates of complications to be less than established rates via a microsurgical approach.

POSTOPERATIVE CARE AND FOLLOW-UP

Following endoscopic transsphenoidal procedures, patients must be observed very closely for evidence of visual dysfunction, epistaxis,

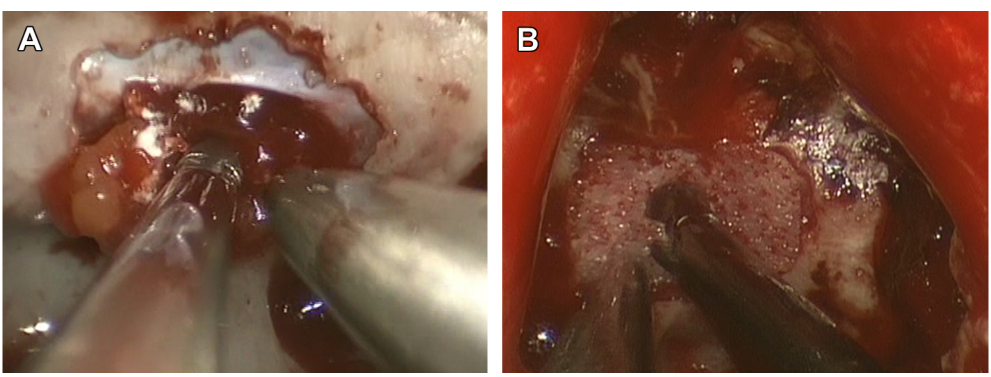

Fig. 16. The reconstruction stage. (*A*) The sella is packed and (*B*) an epidural inlay is placed to aid in buttressing the absorbable graft.

neurologic deterioration, and hormonal deficits, including diabetes insipidus. Most patients are discharged home on postoperative day 2 or 3. In most patients, serum sodium levels and urine output are followed every 6 to 8 hours for the first 48 hours. Patients with any evidence of new hypocortisolemia must be adequately replaced. Patients with functional pituitary adenomas typically undergo basic nonstimulation hormonal testing (serum prolactin, cortisol, or growth hormone) on postoperative days 1 and 2. If nasal packing is used (a minority of cases), it is typically removed on postoperative day 1. Following discharge, patients usually follow-up in clinic 1 week after the operation, with a routine serum sodium level obtained on postoperative day 7 to rule out occult hyponatremia.[36] Routine early postoperative imaging is not performed in most patients. Most patients will undergo standard MRI 3 months following the operation.

SUMMARY

Despite its relatively short existence in the realm of transsphenoidal resection of pituitary lesions, the endoscopic approach has been extensively refined and is quickly becoming the preferred technique over microsurgical transsphenoidal approaches. With increasing exposure to this technique in both residency training programs and within the practicing community, future generations of neurosurgeons will become more adept at this approach and its use will likely become more widespread. Long-term studies with larger numbers of patients will be needed to fully compare endoscopy and microsurgery for pituitary tumor resections; however the current literature is clear that the endoscopic technique leads to equal or improved rates of remission with equal or fewer rates of complications. The future of neuroendoscopy for the resection of pituitary lesions will likely be based on continued miniaturization of the endoscope camera and optical technology, innovation in design of surgical instrumentation, application of 3D cameras and viewing systems to compensate for the loss of depth perception, and introduction of robotics.[1] Combined with increasing surgeon experience and comfort using the endoscopic technique, these advances will likely contribute to improved surgical outcomes in the future.

REFERENCES

1. Zada G, Liu C, Apuzzo ML. “Through the looking glass”: optical physics, issues, and the evolution of neuro-endoscopy. World Neurosurg 2012;77(1):92–102.
2. Jane JA Jr, Han J, Prevedello DM, et al. Perspectives on endoscopic transsphenoidal surgery. Neurosurg Focus 2005;19(6):E2.
3. Doglietto F, Prevedello DM, Jane JA Jr, et al. A brief history of endoscopic transsphenoidal surgery—from Philipp Bozzini to the First World Congress of Endoscopic Skull Base Surgery. Neurosurg Focus 2005;19(6):E3.
4. Lindley T, Greenlee JD, Teo C. Minimally invasive surgery (endonasal) for anterior fossa and sellar tumors. Neurosurg Clin N Am 2010;21(4):607–20.
5. Guiot G, Rougerie J, Fourestier M, et al. Intracranial endoscopic explorations. Presse Med 1963;71: 1225–8 [in French].
6. Apuzzo ML, Heifetz M, Weiss MH, et al. Neurosurgical endoscopy using the side-viewing telescope: technical note. J Neurosurg 1977;16:398–400.
7. Jankowski R, Auque J, Simon C, et al. Endoscopic pituitary tumor surgery. Laryngoscope 1992;102(2): 198–202.
8. Jho HD, Carrau KL. Endoscopy assisted transsphenoidal surgery for pituitary adenoma: technical note. Acta Neurochir (Wien) 1996;138:1416–25.
9. Jho HD, Carrau RL. Endoscopic endonasal transsphenoidal surgery: experience with 50 patients. J Neurosurg 1997;87(1):44–51.
10. Cappabianca P, Alfieri A, de Divitiis E. Endoscopic endonasal transsphenoidal approach to the sell: towards functional endoscopic pituitary surgery (FEPS). Minim Invasive Neurosurg 1998;41:66–73.
11. Prevedello DM, Doglietto F, Jane J Jr, et al. History of endoscopic skull base surgery: its evolution and current reality. J Neurosurg 2007;107:206–13.
12. Goudakos JK, Markou KD, Georgalas C. Endoscopic versus microscopic trans-sphenoidal pituitary surgery: a systematic review and meta-analysis. Clin Otolaryngol 2011;36(3):212–20.
13. Gondim JA, Schops M, de Almeida JP, et al. Endoscopic endonasal transsphenoidal surgery: surgical results of 228 pituitary adenomas treated in a pituitary center. Pituitary 2010;13(1):68–77.
14. Dehdashti AR, Ganna A, Karabatsou K, et al. Pure endoscopic endonasal approach for pituitary adenomas: early surgical results in 200 patients and comparison with previous microsurgical series. Neurosurgery 2008;62(5):1005–15.
15. Zada G, Cappabianca P. Raising the bar in transsphenoidal pituitary surgery. World Neurosurg 2010; 74:452–4.
16. D'Haens J, Van Rompaey K, Stadnik T, et al. Fully endoscopic transsphenoidal surgery for functioning pituitary adenomas: a retrospective comparison with traditional transsphenoidal microsurgery in the same institution. Surg Neurol 2009;72(4):336–40.
17. Hofstetter CP, Shin BJ, Mubita L, et al. Endoscopic endonasal transsphenoidal surgery for functional pituitary adenomas. Neurosurg Focus 2011;30(4):E10.

18. Frank G, Pasquini E, Farneti G, et al. The endoscopic versus the traditional approach in pituitary surgery. Neuroendocrinology 2006;83:240–8.
19. Kabil MS, Eby JB, Shahinian HK. Fully endoscopic endonasal vs. transseptal transsphenoidal pituitary surgery. Minim Invasive Neurosurg 2005;48:348–54.
20. Tabaee A, Anand VK, Barron Y, et al. Endoscopic pituitary surgery: a systematic review and meta-analysis. J Neurosurg 2009;111(3):545–54.
21. Doward N. Endocrine outcomes in endoscopic pituitary surgery: a literature review. Acta Neurochir 2010;152(8):1275–9.
22. Cappabianca P, Cavallo LM, de Divitiis E. Endoscopic endonasal transsphenoidal surgery. Neurosurgery 2004;55:933–41.
23. Ceylan S, Koc K, Anik I. Endoscopic endonasal transsphenoidal approach for pituitary adenomas invading the cavernous sinus. J Neurosurg 2010;112(1):99–107.
24. Zada G, Kelly DF, Cohan P, et al. Endonasal transsphenoidal approach for pituitary adenomas and other sellar lesions: an assessment of efficacy, safety, and patient impressions. J Neurosurg 2003;98:350–8.
25. Jho HD. Endoscopic transsphenoidal surgery. J Neurooncol 2001;54(2):187–95.
26. Jho HD, Alfieri A. Endoscopic endonasal pituitary surgery: evolution of surgical technique and equipment in 150 operations. Minim Invasive Neurosurg 2001;44(1):1–12.
27. Yang I, Wang MB, Bergsneider M. Making the transition from microsurgery to endoscopic transsphenoidal pituitary neurosurgery. Neurosurg Clin N Am 2010;21(4):643–51.
28. Saeki N, Horiguchi K, Murai H, et al. Endoscopic endonasal pituitary and skull base surgery. Neurol Med Chir 2010;50:756–64.
29. Zada G, Agarwalla PK, Mukundan S, et al. The neurosurgical anatomy of the sphenoid sinus and sellar floor in endoscopic transsphenoidal surgery. J Neurosurg 2011;114(5):1319–30.
30. de Divitiis E, Cappabianca P, Cavallo LM. Endoscopic transsphenoidal approach: adaptability of the procedure to different sellar lesions. Neurosurgery 2002;51:699–707.
31. Cappabianca P, Cavallo LM, Esposito F, et al. Sellar repair in endoscopic endonasal transsphenoidal surgery: results of 170 cases. Neurosurgery 2002;51:1365–72.
32. Cappabianca P, Cavallo LM, Colao A, et al. Endoscopic endonasal transsphenoidal approach: outcome analysis of 100 consecutive procedures. Minim Invasive Neurosurg 2002;45:1–8.
33. Berker M, Hazer DB, Yucei T, et al. Complications of endoscopic surgery of the pituitary adenomas: analysis of 570 patients and review of the literature. Pituitary 2011. [Epub ahead of print].
34. Graham SM, Iseli TA, Karness LH, et al. Endoscopic approach for pituitary surgery improves rhinologic outcomes. Ann Otol Rhinol Laryngol 2009;118(9):630–5.
35. Ciric I, Ragin A, Baumgartner C, et al. Complications of transsphenoidal surgery: results of a national survey, review of the literature and personal experience. Neurosurgery 1997;40:225–36.
36. Zada G, Liu CY, Fishback D, et al. Recognition and management of delayed hyponatremia following transsphenoidal surgery. J Neurosurg 2007;106(1):66–71.