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Transnasal Endoscopic Surgical Approaches to the Clivus

Aldo Cassol Stamm, MD[a,b,*],
Shirley S.N. Pignatari, MD[a,b], Eduardo Vellutini, MD[c]

[a]*Federal University of São Paulo, Paulista School of Medicine, São Paulo, Brazil*
[b]*São Paulo ENT Center, Hospital Professor Edmundo Vasconcelos, Rua Afonso Braz 525 CJ13, São Paulo, Brazil 04511-010*
[c]*Department of Neurosurgery, Hospital Oswaldo Cruz, São Paulo, Brazil*

Management of lesions involving the clival region has changed dramatically since the introduction of transnasal microscopic and endoscopic techniques using new advanced surgical instrumentation. However, effective and safe treatment of lesions involving the skull base is still challenging [1]. Several approaches using microscopic surgical techniques have been proposed, seeking to optimize the exposure and minimize the risk of complications. All such microscopic anterior skull base approaches aim to avoid nerve and brain retraction and have been developed along two basic anterior midline routes: the transoral and the transnasal [2,3,4]. The current goal of surgical approaches is to be straighter and faster, avoiding extensive cerebral retraction and presenting a lower rate of morbidity compared with that of classic approaches [5,6].

Nevertheless, despite lower morbidity and fewer complications, the problems of infection, cerebrospinal fluid (CSF) leakage, difficulty controlling intradural bleeding, and lack of appropriate surgical instruments still exist. One of the most difficult remaining challenges is the repair of large dural defects [1].

Surgical anatomy

Any transnasal endoscopic surgical approach to the clival region will necessarily involve the sphenoid sinus, and therefore anatomic knowledge of this paranasal sinus is imperative.

* Corresponding author.
E-mail address: centrodeorl@osite.com.br (A.C. Stamm).

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Sphenoid sinus

The sphenoid sinus varies in shape and size and is asymmetrically divided into two parts by an irregular septum. The thin lateral wall of the well-developed sphenoid sinus forms the medial wall of the cavernous sinus. The intracavernous portion of the internal carotid artery (ICA) is the most medial structure within the cavernous sinus and, in well-developed sphenoid sinuses, produces a bony elevation in the lateral wall of the sinus called the carotid prominence. The carotid prominence is divided into presellar, infrasellar, and retrosellar segments [7]. The presellar segment corresponds with the anterior vertical segment and the anterior bend of the intracavernous portion of the ICA. The infrasellar segment corresponds with the short horizontal portion of the carotid, and the retrosellar segment reflects the posterior bend and posterior vertical segment.

The optic canal is often partially encircled by the sphenoid sinus and creates a bony bulge in the superoanterior portion of its lateral wall. The bony depression between the optic canal and the presellar segment of the carotid prominence is called the *opticocarotid recess* and extends a variable distance into the optic strut. The bony lateral sphenoid sinus wall over the ICA and the optic nerve is usually very thin and may be absent in some areas. Although Lang [8] observed that the canal of the optic nerve was dehiscent in 6% of cases, Seibert [9] found that the canal of the optic nerve bulged into the sphenoid sinus in 57% of cases and that 1% had no bony canal. Seibert [9] also noted that the horizontal portion of the intracavernous carotid artery extended prominently into the sphenoid sinus in 67% of cases and its bony covering was dehiscent in 6%. In his series, the maxillary nerve was prominent in the sphenoid sinus in 48% of specimens and dehiscent in 5%, and the pterygoid nerve (vidian) was prominent 18% of the time.

Clivus

The clivus separates the nasopharynx from the posterior cranial fossa. It is composed of the posterior portion of the sphenoid body (basisphenoid) and the basilar part of the occipital bone (basiocciput) and is further subdivided into upper, middle, and lower thirds. The upper third of the clivus is at the level of the sphenoid sinus and is formed by the basisphenoid bone, including the dorsum sella. The middle clivus corresponds with the rostral part of the basiocciput and is located above a line connecting the caudal ends of the petroclival fissures. The lower third of the clivus is formed by the caudal part of the basiocciput. The intracranial surface of the upper two thirds of the clivus faces the pons and is concave from side to side.

The extracranial surface of the clivus gives rise to the pharyngeal tubercle at the junction of the middle and lower clivus. The upper clivus faces the roof of the nasopharynx that extends downward in the midline to the level of the pharyngeal tubercle (Fig. 1A, B).

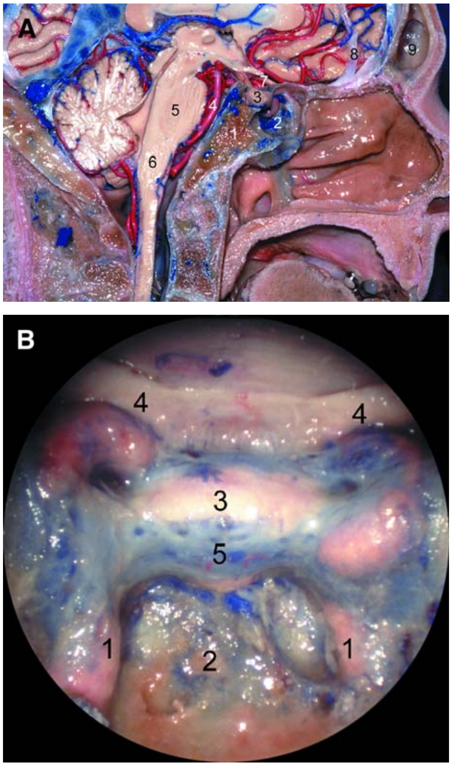

Fig. 1. (*A*) Midline sagittal section of the nasal cavity, sphenoid sinus, clivus, and adjacent structures (1, clivus; 2, sphenoid sinus; 3, pituitary gland; 4, basilar artery; 5, pons; 6, medulla; 7, optic nerve; 8, frontal lobe; 9, frontal sinus). (*B*) Endoscopic view of the posterior wall of the sphenoid sinus (1, prominence of the internal carotid arteries; 2, clivus; 3, anterior sellar wall; 4, optic nerves; 5, intercavernous sinus).

The upper and middle clivus are separated from the petrous portion of the temporal bone on each side by the petroclival fissure. The basilar venous plexus is situated between the two layers of the dura of the upper clivus and is related to the dorsum sella and the posterior wall of the sphenoid sinus. It forms interconnecting venous channels among the inferior petrosal sinuses laterally, the cavernous sinuses superiorly, and the marginal sinus and epidural venous plexus inferiorly. The basilar sinus is the largest communicating channel between the paired cavernous sinuses.

The average distance between the left and right internal carotid arteries just below the tuberculum sellae where they are closest to each other is 13.9 mm (range, 10–17 mm). At the anterior wall of the sella, the carotid arteries are separated by a distance of 20 mm (range, 13–26.5 mm) and by that of 17.4 mm (range, 10.5–26.5 mm) at the level of the clivus [7]. Jho and Ha [10] found the average width between the carotid arteries at the sellar floor level to be 16 mm (range 12–22 mm), and 19 mm (range 14–23 mm) at the lower end of the carotid arteries.

Retroclival region

Although most of the structures of the suprasellar area, cavernous sinus, and retrosphenoid sinus can be reached through the sphenoid sinus, the transnasal transclival endoscopic anatomy of the basal cisterns and posterior fossa through this sinus are not familiar to many surgeons [11].

When all the bone of the posterior and lateral walls of the sphenoid sinus has been removed, only periosteum covers the underlying anatomy. The tectorial membrane protects the clival dura in the middle and lower clivus. When the external layer of the dura is opened, the basilar venous plexus and cranial nerve VI on each side can be seen. The average distance between the abducens nerves (cranial nerve VI) at the dural emergence is 19.8 mm [12].

After opening the inner layer of the clival dura, the 0° endoscope shows the vertebral arteries, basilar artery and its branches (superior cerebellar arteries, anterior inferior cerebellar arteries [AICA]), posterior cerebral arteries, brain stem, mammillary bodies, and intradural pathway of cranial nerves III, IV, V, and VI. Just above the pituitary gland, the pituitary stalk, optic nerves, and optic chiasm can be seen. By introducing a 30°- or 45°-angled endoscope, the cerebellopontine angle, cranial nerves VII and VIII, lower cranial nerves, and retrosellar region (Fig. 2) can be viewed.

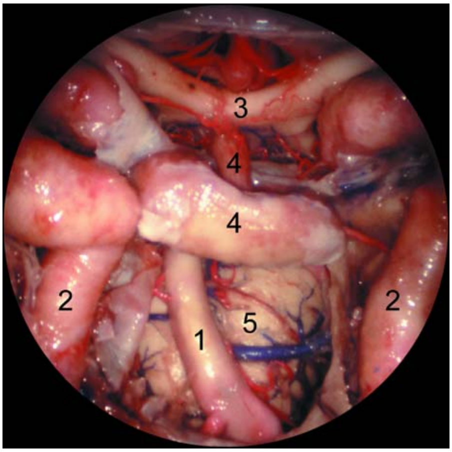

Fig. 2. Endoscopic view of the posterior fossa after the removal of the posterior wall of sphenoid sinus and upper clivus (1, basilar artery; 2, internal carotid arteries; 3, optic nerves and chiasm; 4, pituitary gland and pituitary stalk; 5, brainstem).

Preoperative evaluation

The success of any skull base procedure depends on several factors, including a thorough clinical history, a careful preoperative evaluation, a well-developed surgical plan, and physician–patient conversations that include a frank discussion of the diagnosis, surgical plan, possible complications, and physician and patient roles in the anticipated postoperative care plan.

Physical examination includes endoscopic assessment of the nasal cavity performed with the patient in a semisitting position. The nasal cavity is prepared with a topical anesthetic solution containing a vasoconstrictor. The examination is performed with rigid 4-mm 0° and 45° endoscopes. The flexible 3.2-mm endoscope is preferable for children and a straight 2.7-mm endoscope is occasionally used.

Preoperative image studies should include coronal, axial, and sagittal CT images of the sinuses and skull base as essential parts of the assessment of all skull base lesions. In addition to diagnostic information, CT permits assessment of critical anatomic information important during surgery, such as the presence and extent of erosions of the skull base; integrity of the medial orbital wall; position of the anterior skull base vessels; integrity and degree of aeration of the paranasal sinuses (particularly the sphenoid sinus); location and presence of intersinus septae; position of the internal carotid arteries, optic nerves, and cavernous sinuses; relationships among the ethmoid sinuses and the orbits and optic nerves; relationship between the roof of the ethmoid sinuses and the cribriform plate; and the presence of an Onodi cell. When used in conjunction with an image guidance system, the CT can also provide three-dimensional reconstruction of the patient's skull base region during surgery.

MRI is important in showing the morphology of the soft tissues and the presence of fluid, but is not helpful in assessing bony architecture. MRI helps differentiate between neoplastic or inflammatory tissue and retained secretions, and clarify the diagnosis of skull base malformations when meningoencephalocele, meningocele, or nasal gliomas are suspected. MRI is also valuable in patients who have erosion of the lateral sphenoid wall.

Magnetic resonance angiography (MRA) assesses the structure of medium to large arteries and should be considered for visualizing the relationship between the basilar and internal carotid arteries in patients who have erosion of the lateral and posterior sphenoid walls.

Angio-CT is a recent technology that allows simultaneous visualization of bony and vascular structures. Venous and arterial structures can be seen separately (venous phase and arterial phase) or together (part venous phase and part arterial phase). Angio-CT is especially useful in assessing the internal carotid and vertebrobasilar systems. Venous structures of particular surgical interest include the cavernous sinus, inferior and superior intercavernous sinuses, and the basilar venous plexus. This technology allows

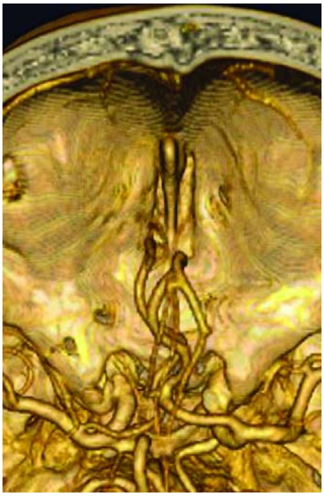

Fig. 3. Three-dimensional model of an angio CT showing anterior cranium seen from above and showing the relationships between the internal carotid and the vertebrobasilar arterial systems.

surgeons to better plan any surgical procedure, especially those involving the parasphenoidal regions and the anterior skull base (Fig. 3).

Although conventional angiography is not routinely performed, it can provide essential information in some specific situations. If a lesion is suspected to involve, impinge on, or displace the ICA, the surgeon must have accurate preoperative knowledge of the position of the ICA and its relationship to the lesion, especially when the transnasal transsphenoidal approach is contemplated (ie, accessing the skull base through the posterior and lateral wall of the sphenoid sinus). Angiography is also helpful for verifying the functional integrity of the circle of Willis, determining the extent of any carotid artery narrowing or occlusion, and differentiating an aneurysm from a tumor.

Operative technique

The patient is prepared as usual for transnasal endoscopic-assisted surgery. The patient is positioned supine on the operating table with the dorsum elevated 30° and the head extended 15° and turned toward the surgeon. No head fixation is necessary.

Transnasal endoscopic-assisted surgery of the skull base is performed under general controlled hypotensive anesthesia. Cottonoids containing adrenaline 1:2000 are placed in the nasal cavity, especially over the areas of surgical access. These cottonoids are left in place for approximately 10 minutes before the surgical procedure begins. If the surgical access is through the nasal septum, the septum is infiltrated with lidocaine with adrenaline 1:100.000. If necessary, adrenaline-soaked cottonoids are used for hemostasis during the surgery. If a CSF fistula is suspected, intrathecal fluorescein can be introduced at the beginning of the surgical procedure to facilitate its precise location [13]. If an image-guided system may be used, the headframe is set up for calibration.

Instrumentation

Clivus surgical procedures are performed with the endoscopes attached to an endocamera and a video monitor system. Most commonly, 4-mm endoscopes of 0° and 45° are used. In conjunction with Karl Storz Inc., we are developing a 5-mm wide-angled 0° telescope for these procedures to increase the field of view and illumination. Although conventional surgical instrumentation can also be used, most of the microendoscopic surgical instruments for these cases are slightly longer and thinner, but just as strong or stronger. Most have an articulation located at the edge, allowing adequate visualization of the operative field. Extra-long handpieces for the surgical drill are essential and are used almost exclusively with diamond burrs of various sizes. Medtronic Xomed has developed a new generation of high-speed drills that incorporate suction–irrigation functions to reduce operative time and allow more accurate dissection. Our initial experience has been very promising. Suction cannulas should have a blunted edge to avoid unnecessary trauma and mucosal bleeding. Contemporary suction elevators for septoplasty can elevate and cut tissue, aspirate blood, and allow the surgeon to operate the suction elevator with one hand while holding the endoscope with the other. Initial evaluation of the structures can be accomplished with a double-ended probe called a *seeker/palpator*. A Freer elevator is another useful instrument that has semisharp and blunt ends. The semisharp end can incise and dissect the mucosa, whereas the blunt end can be used to palpate and displace structures of the nasal cavity, such as the middle turbinate.

Monopolar and bipolar electrocautery permit the surgeon to control bleeding during the surgical access (bleeding from the incision of the nasal septum and from the septal artery that lies on the anterior wall of sphenoid sinus). Bleeding from the basilar venous plexus is not coagulated. Compression with Surgicel packing (Johnson & Johnson, New Brunswick, New Jersey) and obliteration of involved bony channels using diamond burrs or bone wax are helpful. Only a bipolar system of coagulation should be used to control venous or arterial intradural bleeding.

Powered instrumentation (eg, microdebriders) was initially developed for soft-tissue shaving and represents a major advance in transnasal endoscopic-assisted surgery. The instruments have multiple functions, including suction, cutting, and irrigation. Newer instruments with curved blades and burrs are able to remove bone and debulk some tumors. The newer microdebriders also produce a more precise cut of the diseased tissue, avoiding mucosal stripping, and are accompanied by continuous irrigation that improves visualization and diminishes blood loss. The new image guidance systems are precise and have been very helpful in some cases of clivus surgery. These systems of tridimensional navigation provide important information about the location of anatomic structures in the operative field and create an individual anatomic map generated from a preoperative CT. They are particularly useful in identifying the ICA and in accessing the petrous apex when lesions such as cholesterol granuloma are present. This system reduces the chances of surgical complications because it provides the surgeon with an exact anatomic location of a surgical instrument [1,14].

Transnasal–transsphenoidal surgical approaches to the clivus

Several transnasal–transsphenoidal approaches to the clivus have been described [15], including the transnasal direct and transseptal (combined with or without a transethmoidal approach). The choice of the appropriate transnasal technique for each patient depends on the nature, location, and extent of the lesion.

The clival bone can be removed from the floor of the sella to the foramen magnum in the craniocaudal dimension and laterally from one to another ICA with a high-speed drill. When the distance between the two internal carotid arteries is narrow, the transclival surgical access to the posterior fossa is much more difficult.

We use the following classification for transnasal surgical approaches:

1. Transnasal direct
2. Transseptal (anterior incision, posterior incision)
3. Transnasal with removal of the posterior part of the nasal septum (two-nostril approach).
4. Transnasal combined with transethmoidal (middle turbinate removal)

Transnasal direct

The operation is performed through one nostril. If the nasal cavity is very narrow and the passage of the endoscope and operating instruments is limited because of a septal deviation, septoplasty is performed first. After the middle and superior turbinates, the posterior region of the nasal septum, and the choanal arch have been identified, the ostium of the sphenoid sinus is probed with the seeker. To improve access, the superior turbinate is identified and removed with a through-cutting forceps. When the surgical access is very narrow, the posterior portion of the middle turbinate can also be removed with a microscissors.

The initial opening of the sphenoid sinus is made with a micro-Kerrison punch, beginning at the ostium. The sphenoidotomy is enlarged inferiorly and laterally while carefully avoiding or cauterizing the septal artery that crosses the anterior wall of the sphenoid sinus in that region. The 4-mm

0° endoscope is used for this step. This approach can be particularly useful for the following clivus lesions: CSF fistula, clivus meningocele, clivus mucocele, and bacterial or fungal infections that erode the sphenoid sinus and involve the clivus.

Transseptal

The transseptal approach was conceived to provide midline access to the sphenoid sinus region through the nasal septum, avoiding damage to the structures in the nasal cavity and avoiding the lateral wall of the sphenoid sinus and the nearby carotid artery and optic nerve. The transseptal approach has been particularly useful in accessing the clivus, sella, and parasellar regions because these are midline structures.

The surgeon first performs a submucoperichondrial and submucoperiosteal infiltration using lidocaine (2%) and epinephrine (1:100.000), producing a hydraulic dissection that facilitates surgical elevation. A vertical hemitransfixion incision is made at the caudal edge of the septal cartilage and septal flaps are elevated as in performing a septoplasty. The osseocartilaginous junction (septal cartilage, ethmoid plate, and vomer) is disarticulated using the suction elevator, preserving the uppermost part of the osseocartilaginous junction to avoid postoperative dorsal nasal saddling. The posterior attachment of the septum to the perpendicular lamina of the ethmoid is fractured. The posterior part of the septal bone, which obstructs access to the sphenoid rostrum, is resected using a Jansen-Middleton forceps. The mucoperiosteum of the anterior wall of the sphenoid sinus is elevated until the sinus ostia on both sides are visualized. At this point, the anterior wall of the sphenoid sinus is entirely exposed. The sphenoid rostrum and the anterior wall are then opened with a chisel and are enlarged with a micro-Kerrison punch or high-speed drill. The sphenoidotomy is made large enough to allow easy simultaneous introduction of a 4-mm endoscope and a surgical instrument.

Although the caudal hemitransfixion incision is useful when a simultaneous correction of a septal deviation is necessary, making the initial septal incision more posteriorly, closer to the rostrum of the sphenoid sinus, is often advantageous. Pituitary tumors and inverted papillomas occasionally recur in the sphenoid sinus, and in these situations a more posterior incision avoids repeated dissection of scarred septal flaps. For this procedures, a vertical transfixion incision is made 1.5 cm anterior to the sphenoid sinus ostium, joining a second horizontal incision 1 cm below the superior edge of the nasal septum. The mucoperiosteum of both sides can be removed or just retracted laterally, and the bony nasal septum is then removed. If a dural defect is present at the end of the procedure, the mucoperiosteal flap can be used in the dural repair.

The transseptal approach to the sphenoid sinus can be extended to access the sella, parasellar regions, petrous apex, clivus, and cavernous sinus.

Transnasal with removal of the posterior part of the nasal septum (two-nostril approach)

The posterior part of the nasal septum can be removed to enlarge the operative field. The septal mucosa can be elevated and retracted on one or both sides and then replaced or removed at the end of the procedure. This modification permits two surgeons to work simultaneously, one through each nostril. The use of three or four instruments, including the endoscope, facilitates tumor removal and control of any intradural bleeding. It is also very helpful when removing large lesions in the posterior third of the nasal cavity, sphenoid sinus, clivus, sella, and parasellar regions (especially highly vascularized tumors), and is essential in cases with intradural extension.

Transnasal direct combined with transethmoidal (middle turbinate removal)

When a larger operative field is desired, the transethmoidal approach may be combined with the direct transnasal approach. This combined approach is particularly useful for clivus chordoma, petrous apex lesions, and lesions that extend to the lateral recess of the sphenoid sinus.

First, an ethmoidectomy is performed beginning with the resection of the uncinate process and followed by resection of the ethmoid bulla and the remaining ethmoid cells. During the resection of the posterior ethmoid cells, the surgeon must correlate direct observation and intraoperative review of the CT scan to determine whether an Onodi cell is present, and if so, to understand its relationship to the optic canal and ICA.

The initial opening of the sphenoid sinus is made with a delicate curette or an atraumatic aspirator medially and inferiorly. The sphenoidotomy is then enlarged using a micro-Kerrison punch, incorporating the natural ostium into the opening.

Removal of the middle turbinate is usually necessary to create a single cavity between the nasal septum and the medial wall of the orbit. When an even larger surgical field is needed, bilateral ethmoidectomy and resection of both middle turbinates are performed. The middle turbinate mucoperiosteum can be used as a free graft to repair dural defects that were created by the lesion or its removal.

Transsphenoidal and transclival approaches to the cavernous sinus

Although anterior approaches offer a more direct anatomic approach to the structures beyond the clivus, the risks for CSF leakage and infection limit most of the previously mentioned approaches to extradural lesions, especially those that traverse a potentially unsterile operative field [12]. The major advantage of the midline transfacial approaches is the direct anterior surgical access through the large spaces of the nasal cavity, nasopharynx, oral cavity, and paranasal sinuses. However, these midline routes are restricted by critical neurovascular structures such as the ICA, optic nerve, cavernous sinus, cranial nerves, and orbital contents [16].

The transnasal endoscopic-assisted surgical technique begins by using one of the surgical approaches to the sphenoid sinus (transnasal direct, transethmoidal, or transseptal). A micro-Kerrison punch is used to obtain a wide opening of the anterior sphenoid sinus wall. The floor of the sella, the two carotid protuberances, the medial aspect of the optic canals, and the upper clivus are identified. The sinus mucosa that lines the clival area is reflected carefully, exposing the clival bone. The bone is initially removed using a drill system with a diamond burr and continued carefully with a micro-Kerrison punch if necessary (Fig. 4). The clival bone is usually removed as far as the floor of the sella superiorly, the foramen magnum inferiorly, and the bony canals of the sixth cranial nerves, the internal carotid arteries, and the occipital condyles laterally. This technique is used for extradural lesions (Fig. 5A, B). To obtain an intradural exposure, the external layer of the dura is first incised and the basilar venous plexus and cranial nerve VI are encountered. Bleeding in the plexus cannot be cauterized safely but usually can be controlled with small pieces of Surgicel. Large lesions often encroach on and obliterate much of the plexus, but if the lesion is not large or the plexus not completely compressed, profuse and intense bleeding can occur. Control of this bleeding requires judicious packing, time, patience, and experience.

The internal layer of the dura at the level of the middle and superior clivus must be opened with great care to avoid injury to the underlying basilar artery. Once the dura is opened and minor bleeding is stopped using bipolar coagulation, the endoscopes can finally be introduced carefully into the intradural space, and the major vessels of the posterior fossa (eg, basilar artery and branches; AICA; vertebral arteries; superior cerebellar and posterior

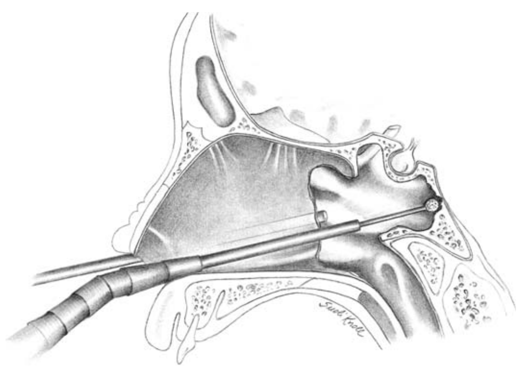

Fig. 4. Schematic drawing showing a modified transseptal approach to the posterior sphenoid sinus wall (clivus). A long handpiece with diamond burr is used to remove the bone of the upper clivus.

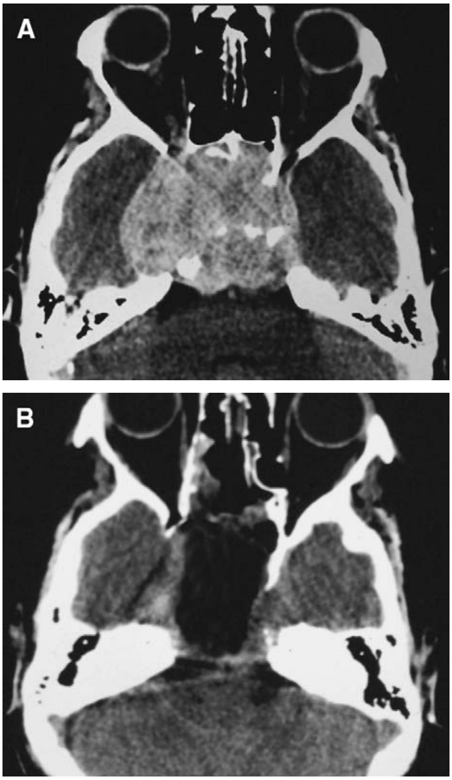

Fig. 5. (*A*) Preoperative axial CT of a patient who has an extradural clivus chordoma. (*B*) Postoperative axial CT of the patient seen in Fig. 5A after endoscopic resection of the extradural clivus chordoma.

cerebral arteries); the intradural course of cranial nerves III, IV, V, and VI; the brainstem; and the mammillary bodies can be identified. The cerebellopontine angle, cranial nerves VII through XII, and the retrosellar regions are best visualized using endoscopes of 30°, 45°, or 70° (Fig. 6).

Large dural defects at the clivus region are difficult to repair. We usually seal such defects with fat, fascia lata, and nasal septal mucoperiosteum/middle turbinate grafts. These grafts are kept in place with fibrin glue and pieces of Gelfoam (Pharmacia & Upjohn Company, Kalamazoo, Michigan). The nasal cavity is packed with Merocel (Medtronic Xomed, Jacksonville, Florida) for 3 to 5 days. A lumbar subarachnoid drain is not often necessary. Broad-spectrum antibiotics are used for 10 days.

The transsphenoidal transclival approach with removal of the posterior nasal septum has two main advantages: avoiding cerebral retraction and a decreased incidence of injury to the lower cranial nerves. In addition, the approach is direct without external incisions, is quick, and best preserves the anatomic structures. Although endoscopes do not allow a three-dimensional

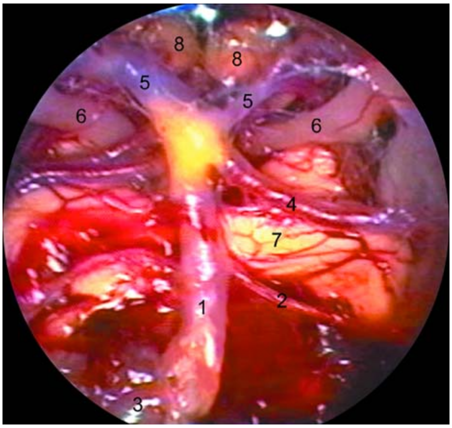

Fig. 6. Surgical endoscopic view during a transseptal transclival approach (1, basilar artery and branches; 2, AICA; 3, vertebral artery; 4, superior cerebellar artery; 5, posterior cerebral arteries; 6, intradural course of cranial nerve III; 7, brainstem; 8, mamillary bodies).

perspective, they provide a close view of the operative field from different angles. However, this technique requires the surgeon to work in a narrow operative field limited by critical neurovascular structures, such as internal carotid arteries; optic nerves; cavernous and basilar sinuses; and the pituitary gland. The risks for major intradural bleeding, CSF leakage, and meningitis must not be taken lightly. This technique is often used for clivus chordoma removal (Fig. 7A, B).

Transclival approach to the petrous apex

The transclival approach to the petrous apex can be useful for biopsy and drainage purposes. This type of surgical access can be particularly helpful in selected cases of cholesterol granuloma of the petrous apex because complete excision is unnecessary (Fig. 8A, B). Although surgical drainage is usually accomplished through the temporal bone, the transsphenoidal transclival endoscopic approach may be indicated when the lesion abuts the posterior and lateral wall of the sphenoid sinus. In these cases, an image guidance system can be very helpful, especially for precise identification of the ICA and optic nerve [17].

Repair of cerebrospinal fluid leaks and dural defects

CSF leakage can occur during any skull base procedure. The skull base surgeon must anticipate and identify intraoperative dural defects and be prepared to treat them as part of the planned surgical procedure. The same principles apply when CSF fistulas are repaired as a primary procedure.

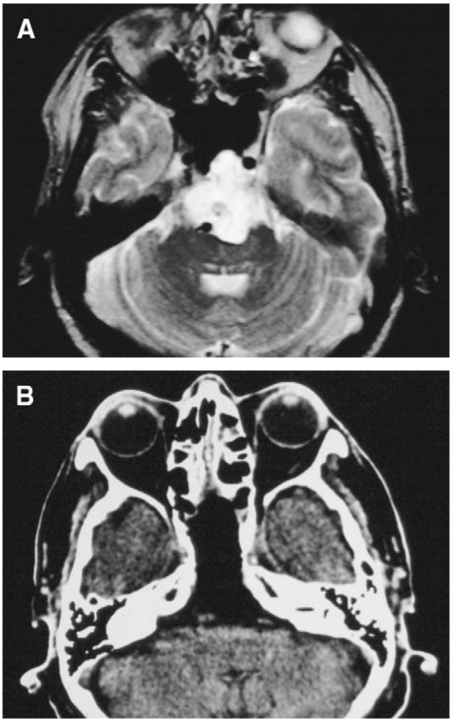

Fig. 7. (*A*) Preoperative axial MRI of a patient who has a clivus chordoma with intradural extension. (*B*) Postoperative axial CT of the same patient shown in Fig. 7A after endoscopic resection.

The surgical techniques for repairing a CSF fistula have the same principles, regardless of the location of the fistula: identifying the site of the fistula, and repairing it with a free mucoperiosteal graft from the inferior or middle turbinate or from the nasal septum. For large defects, we use a two-layer closure of fascia lata and mucoperiosteum, sealed with fibrin glue and covered with Gelfoam and nasal packing [18]. Synthetic material such as Duragen (Integra Life Sciences Corporation, Plainsboro, New Jersey) and Duraform (Codman, Raynham, Massachusetts) may also be used to help seal the fistulas. Lumbar subarachnoid drain should be initially avoided in cases of large defects because of the possibility for tension pneumocephalus. If a low-volume fistula appears a few days later, it may be treated with lumbar catheter placement alone.

Authors' experience

From 1995 to 2005, the authors endoscopically removed 36 lesions of the clivus region without an external approach. Not all of the lesions originated from the clivus; some arose from adjacent regions. The most frequent clivus

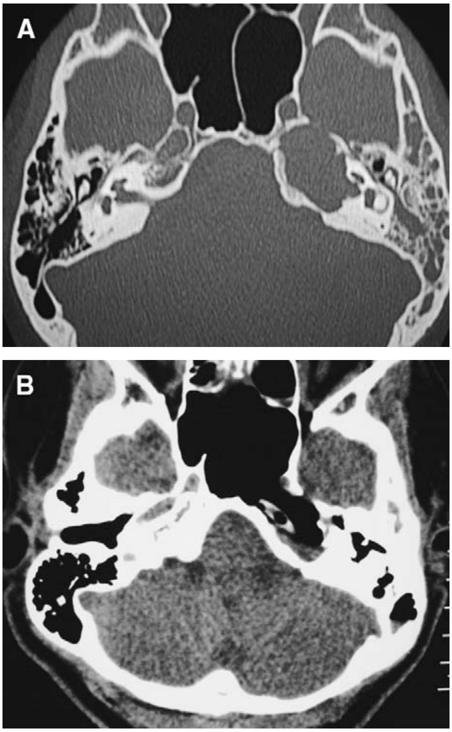

Fig. 8. (*A*) Axial CT of a cholesterol granuloma of the petrous apex. (The patient presented with left cranial nerve VII paralysis and left mixed hearing loss). (*B*) Postoperative CT of the same patient shown in Fig. 8A. (Note the apical communication into sphenoid sinus and presence of drainage catheter.)

lesions in our series were clivus chordoma; primary CSF fistulae; meningocele and meningoencephalocele; and clivus teratoma. Clivus-related lesions included angiofibroma, cholesterol granuloma of the petrous apex, and infection of the sphenoid sinus (Table 1).

Complications

Every clivus surgical procedure has potential complications. Prevention of the complications of transnasal endoscopic-assisted surgery of skull base begins with an adequate preoperative evaluation of the patient, including history of medication use and previous operations. High-resolution CT in coronal and axial projections with sagittal reconstruction, MRI, and sometimes angiography are essential in planning the procedure and executing it safely with the lowest possibility of complications.

Complications can be classified as *minor* or *major* according to severity, and as *immediate* or *delayed* according to time of appearance. Minor

Table 1
Frequency of clivus lesions operated through endoscopic transnasal approach (1995–2005)

Clival lesions	Number
Clivus chordoma	13
Cholesterol granuloma (petrous apex)	04
Cholesterol granuloma (clivus)	02
Primary CSF fistula	04
Traumatic CSF fistula	02
Clival meningocele	02
Intraclival mucocele	02
Fungal disease	04
Clivus teratoma	01
Malignant tumors	03

complications present little morbidity and do not compromise the life of the patient, although they may be annoying and troublesome. Most minor complications resolve with time and conservative treatment. However, major complications present significant morbidity and the possibility of mortality. Most orbital complications stem from direct injury to the optic nerve or the extraocular muscles, or from arterial or venous bleeding within the rigid bony orbit. These injuries can result in diplopia, hematoma, proptosis, decreased visual acuity, or blindness (which can be temporary or permanent). Blindness secondary to orbital hematoma can be reversible and mandates prompt hematoma evacuation to relieve the increased pressure compromising the blood supply to the retina or the optic nerve. Direct or indirect damage to the optic nerve usually occurs at the superolateral sphenoid sinus wall or in the posterior ethmoid cells.

Intracranial complications can result from direct injury to brain, cranial nerves, meninges, blood vessels, or venous sinuses. The resulting deficits reflect the loss of function of damaged structures in the case of brain and cranial nerves, the effects of loss of vascular supply to critical areas (stroke), or the mass effect of a resulting hematoma. Additionally, CSF leakage can cause symptoms directly and predispose to meningitis, and air entering the brain (pneumocephalus) can cause mass effect symptoms.

Bleeding is a risk in any surgical procedure, but seldom are so many important vessels susceptible to injury. The transnasal approaches visualize and place at risk the anterior and posterior ethmoid arteries; the sphenopalatine and maxillary arteries and their branches; the ICA; the anterior cerebral, basilar, and vertebral arteries and their branches; and the venous sinuses of the skull base (the cavernous sinus, basilar venous plexus, and the anterior intercavernous sinus).

Severe injuries of the ICA can be catastrophic and lethal. In cases of minor injuries, we recommend the following measures: 1) packing the sphenoid sinus and nose; 2) compressing the ICA in the neck; 3) temporarily lowering the blood pressure (hypotensive anesthesia); 4) blood transfusion as necessary; and 5) neurosurgical assistance. After controlling the bleeding, angiography is mandatory to evaluate the possibility of pseudo-aneurysm formation and the cross-circulation, because an occlusion of the ICA or stents may be needed.

The most frequent immediate complications are CSF leakage, intraoperative bleeding, orbital hematoma, brain injury, and intrasellar complications, which can include injuries of the diaphragma sella; arachnoid membrane; pituitary stalk; intra-arachnoid vascular structures; and the hypothalamus, optic nerve, and chiasm and their surrounding vessels. Injuries to cranial nerves III and VI are uncommon except in the transsphenoidal transclival approaches. Delayed complications include progressive loss of vision or smell, meningitis, bleeding, synechia, and infection. The surgeon must also be aware of the possibility of transitory or permanent endocrinologic complications that can result from manipulation, compression, or traction of the pituitary stalk. The surgeon must be able to diagnose acute anterior pituitary insufficiency and manage this condition, or have available appropriate consultants who can.

Postoperative care

The goal of surgical treatment is to assure complete removal of the disease, and the best possible functional result. A satisfactory postoperative result depends on appropriate operative technique and meticulous postoperative care.

Wide-spectrum antibiotics are given during the operation and for 10 days postoperatively. Adequate postoperative care of the operative site requires appropriate instrumentation, including 4-mm 0°, 45°, and 70° endoscopes; straight and curved atraumatic aspirators; and straight and curved microforceps.

We remove all packing 2 to 4 days after surgery (earlier for uncomplicated cases, but no longer than 4 days for extensive procedures or those with more aggressive diseases). The operative cavity is carefully suctioned and any residual bony fragments are removed. A second visit is scheduled between the 10th and 12th day after surgery and the operated cavity is again cleaned of crusts, granulation tissue, clots, and secretions. A third visit is scheduled between the third and fourth postoperative week. By then, the surgical cavity usually appears to be healing well. Image study is recommended 3 months after surgery to verify the postoperative status. CT or MRI is performed earlier if healing does not seem to be progressing satisfactorily or if complications are suspected.

Summary

Transnasal endoscopic-assisted techniques to the clivus region can be safe and effective. Endoscopic-assisted approaches provide improved visualization and are a superior alternative to open surgical approaches in most cases. Nevertheless, problems such as infection, CSF leakage, and difficulty controlling intradural bleeding still remain. Surgeons must always remember that, although high technology such as endoscopes, image-guided surgery systems, imaging studies, and advanced anesthetic drugs were essential for the development and improvement of the skull base surgery, the success of this type of surgery depends on perfect knowledge of the anatomy, intense endoscopic surgery training, and a multidisciplinary partnership.

References

[1] Stamm AC, Pignatari SSN. Transnasal endoscopic-assisted surgery of the skull base. In: Cummings CW, Flint PW, Harker LA, editors. Otolaryngology head neck surgery. 4th edition. Philadelphia: Elsevier Mosby; 2005. p. 3855–76.

[2] Crockard HA. The transoral approach to the base of the brain and upper cervical cord. Ann R Coll Surg Engl 1985;67:321–5.

[3] Draf W, Weber R, Keerl R. Endonasale chirurgie von tumoren der nasennebenhohlen und rhinobasis. Med Bild Dienst 1995;2:13–7.

[4] Harsh GR, Joseph MP, Swearingen B, et al. Anterior midline approaches to the central skull base. Clin Neurosurg 1996;43:15–43.

[5] Alfieri A, Jho HD. Endoscopic endonasal approach to the cavernous sinus. An anatomical study. Neurosurgery 2001;48:1–11.

[6] Jho HD. The expanding role of endoscopy in skull base surgery. Clin Neurosurg 2001;48: 278–305.

[7] Fujii K, Chambers SM, Rhoton AL Jr. Neurovascular relationship of the sphenoid sinus. A microsurgical study. J Neurosurg 1979;50:31–9.

[8] Lang J. Clinical Anatomy of the nose, nasal cavity and paranasal sinus. NY: Thieme; 1989.

[9] Siebert DR. Estudo anatômico de seios esfenoidais em brasileiros adultos [thesis]. São Paulo, Brazil: University of São Paulo; 1992.

[10] Jho HD, Ha HG. Endoscopic endonasal skull base surgery: part 3- the clivus and posterior fossa. Minim Invasive Neurosurg 2004;47(1):16–23.

[11] Zhou D, Patil AA, Rodriguez-Sierra J. Endoscopic neuroanatomy through the sphenoid sinus. Minim Invasive Neurosurg 2005;48:19–24.

[12] Puxeddu R, Lui MWM, Chandrasekar K, et al. Endoscopic-assisted transcolumellar approach to the clivus: an anatomical study. Laryngoscope 2002;112:1072–8.

[13] Stammberger H, Greistorfer K, Wolf G, et al. Surgical occlusion of cerebrospinal fistulas of the anterior skull base using intrathecal sodium fluorescein. Laryngorhinootologie 1997;76: 595–607.

[14] Lam SM, Huang C, Newman J, et al. Computer aided image guided endoscopic sinus surgery in unusual cases of sphenoid disease. Rhinology 2002;40:179–84.

[15] Gibbons M, Sillers MJ. Minimally invasive approaches to the sphenoid sinus. Otolaryngol Head Neck Surg 2002;126:635–41.

[16] Hitotsumatsu T, Matsushima T, Rhoton AL. Surgical anatomy of the midface and the midline skull base. Oper Tech Neurosurg 1999;2:160–80.

[17] Stamm AC, Pignatari SSN, Sebusiani BB, et al. Endoscopic surgery of the paranasal sinuses and skull base by using the image guided system. Rev Bras Otorrinolaringol 2002;68:502–9.

[18] Stamm AC. Micro-endoscopic surgery of the paranasal sinuses. In: Stamm AC, Draf W, editors. Micro-endoscopic surgery of the paranasal sinuses and the skull base. Heildelberg: Springer; 2000. p. 201–36.