REVIEW

Endoscopic endonasal skull base surgery

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Summary Skull base surgery has been transformed by the development of endoscopic techniques. Endoscopic procedures were first used for pituitary surgery and were then gradually extended to other regions. A wide range of diseases are now accessible to endoscopic skull base surgery. The major advantage of the endoscopic endonasal approach is that it provides direct anatomical access to a large number of intracranial and paranasal sinus lesions, avoiding the sequelae of a skin incision, facial bone flap or craniotomy, and brain retraction, which is inevitable with conventional neurosurgical incisions, resulting in decreased morbidity and mortality and, indirectly, decreased length of hospital stay and management costs. Moreover, the increasing number of publications in this field illustrates the growing interest in these techniques. This paper provides a review of endoscopic skull base surgery. The indications and general principles of endoscopic endonasal skull base surgery are described. Progress in exposure and especially reconstruction techniques is described. This progress now allows more extensive resections, while maintaining acceptable morbidity. The limits of this surgery are also discussed; in particular, although this surgery is often described as "minimally invasive", it is not completely devoid of morbidity.

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Introduction

Skull base surgery has been transformed by the development of endoscopic endonasal surgery. These techniques were initially developed for paranasal sinus surgery, but their indications have been gradually extended to include endoscopic resection of pituitary tumours, and then lesions of the clivus, olfactory cleft, planum sphenoidale, but also the petrous apex, or infratemporal fossa.

Endoscopic endonasal surgery provides access to almost all regions of the skull base situated anterior to the foramen magnum (Fig. 1). Tumours are the lesions primarily concerned, but cerebrospinal fluid (CSF) leaks of traumatic or other origin, certain chronic infections and congenital malformations are also accessible to endoscopic surgery.

The growing interest of otorhinolaryngologists and neurosurgeons in this "minimally invasive" surgery is due to the major progress made over recent years: a large number of anatomical studies, variants and innovations in
exposure techniques and especially reconstruction have been reported. Constant progress in imaging, navigation systems, and instrumentation has also largely contributed to the growth of this surgery. The large number of publications reflects the growing interest of surgeons in these new techniques.

We propose a review of the current state of the art of endoscopic skull base surgery: the main indications are discussed, while stressing that some clinical settings remain controversial. Surgical instrumentation and the complementary investigations of the preoperative assessment are described, together with the general principles of the surgical technique, particularly concerning exposure and reconstruction. The limitations of this surgery are also discussed, with particular emphasis on the quality of life of patients following this type of surgery.

Indications

A recent consensus [1] validated the use of endoscopic techniques in the management of benign tumours: pituitary adenomas, craniohypophygiomas, but also inverted papillomas and nasopharyngeal fibromas can be operated via an endonasal approach. Recent publications have also concerned endonasal management of cholesterol granuloma of the petrous apex and petrous apicitis, congenital malformations (meningoencephaloceles), or CSF leaks, showing a comparable or superior efficacy to conventional open surgery [2–4]. These results also apply to children, taking into account the anatomical specificities related to growth of the facial bones, particularly the paranasal sinuses [5].

The follow-up is currently too short to evaluate the long-term results in series of endoscopic resection of meningiomas, optic nerve gliomas, and chordomas of the clivus. The 2010 European consensus nevertheless emphasized the low operative morbidity of this type of surgery, which has been further decreased by progress in the field of reconstruction.

The rare controlled studies on malignant tumours tend to show a comparable efficacy of endoscopic surgery and conventional surgery [6–10]. Nicolai et al., in 2008, published their experience based on a series of 134 patients undergoing endoscopic resection of various malignant tumours, and reported a 5-year disease-specific survival of 91.4% [11]. However, the results of these studies must be interpreted cautiously due to their limited follow-up and their retrospective and non-randomized design.

A major criticism of endoscopic techniques is that they do not allow en bloc resection of the tumour. However, the tumour is also often fragmented in the course of open surgery and the most important aspect is not en bloc resection, but complete resection of the zone of insertion: tumours often present an exophytic growth into paranasal sinuses from a smaller pedicle. Finally, the endonasal approach often allows resection without damaging adjacent healthy tissues, which is not the case with conventional open surgery, in which the skin, bone, and sometimes dura mater are opened to provide access to the tumour, with a risk of tumour seeding.

In conclusion, the available data are currently insufficient to define guidelines for the endoscopic management of malignant tumours, but the rules of cancer surgery probably remain the same for endoscopic surgery and open surgery, which must strive to achieve complete resection with healthy margins, while limiting morbidity.

Instrumentation

Apart from videoendoscopy equipment and standard endonasal instrumentation, endoscopic endonasal skull base surgery may require the use of dedicated instruments [12,13]:

- the microdebrider facilitates exposure time, particularly ethmoidectomy, and can also be used for resection in some cases, or at least for tumour dissection [14]. Some authors propose the use of ultrasonic surgical aspirators (Dissectron®, Cavitron®) for tumour dissection, and ultrasonic bone curettes have also been recently developed [15];
- motors equipped with long handpieces allow drilling of the thickest portions of the skull base. Angled burs are particularly useful in the frontal sinus region [16,17];
- haemostasis systems mainly comprise sheathed monopolar cautery and bipolar forceps. Diode laser is also useful, particularly during mucosal dissection (for example, for creation of a nasoseptal flap);
- navigation systems are widely available and are very useful for intraoperative anatomical localization;
- some authors propose the use of a Doppler probe to localize large vessels [17], but neuronavigation effectively guides the surgeon in the majority of cases;
- the use of an endoscope-fitted irrigation system depends on each team’s usual practices. An endoscope without irrigation system has a much smaller diameter and is therefore easier to use and is less traumatic to the nasal cavity. A simple stream of saline from a syringe delivered by the assistant onto the shaft of the optic endoscope allows rinsing of the endoscope when it is soiled;
• long, small-calibre dedicated instrumentation facilitates soft tissue dissection and intradural surgery.

Preoperative assessment

Imaging
In general, CT and MRI must be performed prior to any form of endoscopic skull base surgery. Imaging visualizes the extent of tumour invasion and helps to plan the operative strategy. CT provides information on the skeletal anatomy of the sinuses and pathological bone lesions, particularly neoplastic osteolysis, by specifying their topography and adjacent structures: internal carotid artery (ICA), skull base foramina.

MRI visualizes soft tissues and their invasion by the tumour. It can visualize invasion of cranial nerves, orbit, infratemporal fossa, parapharyngeal spaces, and nasopharynx, and, more especially, demonstrates dura mater and brain involvement. Contrast-enhanced sequences or TOF sequences show the course of blood vessels, particularly the ICA, and their anatomical relations with the tumour.

CT (and possibly MRI) are performed with an acquisition allowing use of a navigation system. The CT-MRI image fusion, currently under development, should prove useful in very large tumours.

Embolication and occlusion tests
Due to the difficulties of haemostasis in an open cavity such as the nasal cavity, the risk of bleeding must be anticipated and prevented as far as possible. MRI or contrast-enhanced CT can be used to assess the extent of the tumour blood supply and, in the case of a highly vascular tumour, tumour embolization should be performed, when possible via an endovascular approach with devascularization of the tumour pedicle. This procedure should ideally be performed 48 to 72 hours before the surgical operation: a longer interval is associated with a risk of development of a collateral blood supply and inflammatory phenomena that can make dissection more difficult [18]. When the site of the tumour presents a particular risk of damage to the ICA, some authors recommend a carotid occlusion test. Direct percutaneous embolization has been almost completely abandoned due to the major risk of embolic complications [19].

Exposure techniques

Endoscopic endonasal surgery consists of performing operative procedures in 3 dimensions on the basis of two-dimensional images, hence the importance of endoscopic anatomical landmarks in order to guide the operator in relation to the depth of field. It is therefore essential, whenever possible, to operate within a single cavity, sufficiently large to allow visualization of the greatest possible number of endoscopic landmarks, but also to provide sufficient freedom of movement to the operator and the assistant in this frequently four-hand surgery.

Surgical access must be adapted to the planned procedure: it can range from simple unilateral luxation of the middle turbinate to complete bilateral ethmoidectomy, and may require complementary procedures such as resection of the septum and medial maxillectomy. These two procedures allow the creation of a large surgical corridor accessible to four-hand surgery, but also facilitate postoperative endoscopic care and surveillance (Fig. 2).

Haemostasis [20]

As far as possible, the operation should start with devascularization of the tumour pedicle. The endoscopic endonasal approach is particularly useful for devascularization of tumours inserted on the intracranial surface (meningiomas): the endoscopic approach provides direct access to the site of insertion of the tumour [21]. In some cases, devascularization is visualized by a colour change of the tumour. Arterial bleeding (sphenopalatine, ethmoidal and internal maxillary arteries) must be prevented, whenever possible, by preventive haemostasis procedures designed to avoid severe bleeding with sudden retraction of proximal frag-

Figure 2 Endonasal exposure techniques visualized on an axial CT scan (A): resection of the septum, medial maxillectomy, resection of the posterior and lateral walls of the maxillary sinus, and drilling of the root of the pterygoids to provide wide access to the infratemporal fossa and parapharyngeal and retropharyngeal spaces (B).
ments (responsible for dramatic retrobulbar haematoma in the case of ethmoidal arteries). Unexpected bleeding must be treated either by clips or by bipolar electrocoagulation, and, in the last resort, by packing. Venous bleeding, particularly due to damage of the cavernous sinus or pterygoid venous plexus, is difficult to control by coagulation and haemostasis can be ensured by packing with Surgicel® (prolonged if necessary). Considerable progress has been provided by haemostatic matrices such as Floseal®, Tissucol®, or Surgicoll® [22].

At the end of the operation, nasal packing must be adapted to the procedure: a simple pituitary procedure generally does not require any packing, but more extensive resections may require conventional nasal packing, sometimes integrated into the reconstruction procedure.

**Reconstruction**

Many materials are available to reconstruct a dural defect: synthetic materials (equine collagen sponge impregnated with human thrombin and fibrinogen, such as Tachosil®, dural substitute such as Neuro Patch®, or bone substitute such as LactoSorb®), or autologous materials (fat, fragments of turbinate, mucosa or nasal septum removed at the beginning of the operation, conchal cartilage harvested separately, temporalis fascia, fascia lata harvested from the previously draped thigh). Fibrin sealants, such as Tissucol® and DuraSeal® gels are not designed to ensure a lasting seal, but are especially useful to maintain the graft in place, and, by temporarily ensuring a certain watertight seal (as these materials are resorbable), to protect healing and integration of mucosa, turbinate, or fascia lata grafts. The reconstruction material can be maintained if necessary by absorbable (Surgicel®) or nonabsorbable synthetic materials (silastic, gauze packs).

There are no absolute rules concerning closure of a skull base defect [4]. Some authors stress the importance of reconstruction in several planes [23]: arachnoid, bone and dura mater and sinus planes should be reconstructed. In reality, a watertight closure can often be obtained by reconstruction in one plane. Similarly, the value of inlay or overlay grafts has not been formally demonstrated. We propose reconstruction of the various planes concerned by the defect, but the technique and the materials used actually depend on the clinical setting and the surgeon’s usual practice.

No reconstruction is necessary in the absence of meningeal tear and CSF leak, particularly following pituitary surgery. In the case of a small CSF leak, the arachnoid plane could be reconstructed by simple injection of fibrin sealant through the arachnoid defect, and the bone and dura mater can then be reconstructed by a conchal patch placed on the defect, with fibrin sealant.

For larger defects, most authors recommend placing a piece of tissue (e.g. fascia lata) between the intracranial and extracranial compartments, which is maintained in an intracranial-extradural position by a rigid pin (fragment of vomer, septal cartilage, or conchal cartilage), which is then covered by an additional layer. In every case, the development of mucoceles must be prevented by carefully avoiding inclusion of mucosa in the reconstruction [24]: all mucosa must be removed from the surface of the graft and from the edges of the defect. This raw surface also facilitates graft adhesion.

Even larger defects require reconstruction in multiple layers, usually reinforced by a local flap. In the case of resection with opening of the dura in the regions of the clivus, sella turcica, planum sphenoidale, and olfactory cleft, but also when cover of the ICA is required, a nasoseptal flap may be used [25]. This flap must be created at the beginning of the operation with a pedicle based on the nasoseptal artery, a branch of the sphenopatinal artery (Fig. 3). This flap is contraindicated in the presence of direct or adjacent invasion by a malignant tumour. In the case of failure, or when a previous posterior resection of the septum has compromised the blood supply of the nasoseptal flap, a temporalis fascia flap can be used [26].

Other local pedicle flaps have also been used: turbinate flap, galea flap, but which cannot be performed via a strictly endoscopic endonasal approach [27], palatal flap [28], and the facial artery musculomucosal (FAMM) flap [29].

The indications for external lumbar drainage and the need (and duration) of supine bed rest remain controversial, and no practical conclusions can be drawn from a review.

![Figure 3](image-url)  **Figure 3**  Left nasoseptal flap: drawing of the proximal part of the nasoseptal flap with a pedicle based on the sphenopalatine artery (A). Reconstruction by nasoseptal flap after resection of a chordoma of the clivus: postoperative appearance on MRI T2-weighted sequence (B), and on endoscopy (note the wide resection of the septum) (C).
of the literature: these decisions are based on each team’s usual practices [30–32].

It is also important to ensure coverage of the ICA when it is exposed at the end of procedure [33], as cases of reactive carotid arteritis with ischaemic stroke have been reported in patients in whom the ICA was left exposed at the operative site.

Postoperative care

Antibiotic therapy

No consensus has been reached concerning the management of prophylactic and postoperative antibiotics. In a study by Brown et al., published in 2007 [34], 90 patients treated by endoscopic endonasal resection of tumours or encephaloceles of the anterior and middle cranial fossae received single-agent IV antibiotic therapy active against Gram-positive cocci (cephazoline, vancomycin, or clindamycin) for 24 to 48 hours: no patient developed meningitis or intraocular infection.

We administer perioperative IV antibiotic therapy for 24 hours active against Gram-positive cocci possibly followed by broad-spectrum oral antibiotic therapy such as the amoxicillin-clavulanic acid combination in the case of protracted presence of foreign material (balloon catheter, gauze packing, etc.) in the nasal cavities.

The risk of meningitis is essentially observed during the first days after the operation: patients therefore remain in hospital for 5 days for close surveillance of the absence of fever, meningeval syndrome, or cerebrospinal rhinorrhoea.

Endonasal packing and dressings

When nasal packs are placed at the end of operation, they are removed on D1 and silastic splints are removed on D10. In children, nasal packs may need to be removed under nitrous oxide or even general anaesthesia.

The nasal cavity is examined at an outpatient visit on D10: the formation of adherent secretions during healing can be responsible for local superinfection, causing pain, difficult nose breathing, and sometimes systemic symptoms (fever, asthenia) [35]. These complications can be limited by repeated debridement of the nasal cavity under local anaesthesia. Nasal irrigation with saline is prescribed to facilitate clearance of these secretions.

Pituitary function

The pituitary gland and infundibulum can be damaged during access to the sella turcica and planum sphenoidale. An endocrinologist must ensure surveillance of pituitary function and particularly the absence of diabetes insipidus.

Limitations of endonasal skull base surgery

Anatomical limitations

In reality, there are few anatomical limitations to endonasal skull base surgery: anatomical studies [36–40] have shown that most structures encountered during endoscopic endonasal skull base surgery can be either resected or mobilized. For example, in the osteocartilaginous skeleton of the nasal cavities, only the nasal bones and an anterior band of septal cartilage must be preserved in order to maintain the shape of the nose. In particular, medial maxillectomy provides wide access to the posterior wall of the maxillary sinus and, more posteriorly, the infratemporal fossa (Fig. 2). In very experienced hands, the pituitary and infundibulum can be mobilized to provide access to the cisterna interpeduncularis and third ventricle.

One of the main anatomical limitations is the ICA. Accidental damage to the ICA can result in cataclysmic bleeding that is often impossible to control. In some cases, a carotid occlusion test is performed before the operation, but sacrifice of an ICA is associated with a major risk of neurological sequelae. Zanation et al. [2] described a mobilization technique of the paracaval petrosal part of the ICA: this procedure is reserved to highly skilled operators.

Cerebral involvement remains a contraindication to endoscopic surgery for most authors [41]. Optic nerve invasion is also a major limitation, as any resection or mobilization results in permanent visual impairment.

Finally, in the case of cancer surgery, invasion of certain structures requires procedures that cannot be performed via an exclusive endonasal approach: orbital invasion via the inferior orbital fissure or by effraction of periorbital tissues theoretically requires surgical exenteration. The endonasal technique does not allow satisfactory resection of lesions involving the maxilla, nasal bones. Posterior extension into the infratemporal fossa with osteolysis of the greater wing of the sphenoid cannot be treated by an exclusive endonasal approach. Finally, by definition, skin extension constitutes a contraindication to endoscopic surgery.

The preoperative imaging work-up is therefore essential to plan the surgical approach, either for a malignant tumour or a benign tumour: the surgical indication may need to be revised in the presence of invasion adjacent to the optic nerve or cerebral vessels (ICA, but also the basilar trunk, cerebral or cerebellar arteries). Similarly, a lesion to which access is blocked by the optic nerve (even when the optic nerve is not invaded) is not amenable to endoscopic endonasal surgery.

Limitations related to the surgical technique

These limitations are essentially related to haemostasis and CSF leak. Careful anticipation of the risks of bleeding and progress in the field of haemostatic matrices have considerably limited the risks related to bleeding. Careful reconstruction, according to the principles described above, usually allows large resection with a moderate rate of postoperative CSF leak.

Equipment limitations

The equipment required for endoscopic endonasal surgery is relatively common: the endoscopic instrumentation, camera, microdebrider, navigation systems are globally the same as for conventional paranasal sinus surgery. However, some dedicated instruments, such as motors equipped with long or angulated handpieces, and endonasal neurosurgical dissection instruments. Endoscopes, which must provide very precise images, are regularly renewed. The cost of this equipment is therefore considerable, particularly due to the use of disposable items (microdebrider blades). These costs must be weighed up against the costs of conventional open surgery instrumentation (burr-holes, etc.), and especially
the excess cost of prolonged hospitalisation, as patients operated by endoscopic endonasal surgery generally have a shorter hospital stay than those operated by craniotomy.

Technical innovations also open up new prospects in the field of endoscopic surgery: endoscopes and camera systems providing 3D vision, currently under development, appear to facilitate identification of anatomical structures and endoscopic surgical techniques [42,43]: difficulties related to proprioception, and absence of correlation between 3D movements and 2D images would be decreased. Intraoperative imaging will probably become more widely available in the years to come. Recent studies tend to demonstrate the efficacy of intraoperative imaging in terms of the final quality of resection [44–46].

**Surgeon-related limitations**

The learning curve is an important element in the development of this surgery [47,48]. Although otorhinolaryngologists are used to working with endonasal endoscopes, this is not always the case for neurosurgeons, who will therefore have to acquire these techniques.

Sinus surgery is generally performed with two hands, and four-hand surgery remains unusual for most surgeons. Once again, both surgeons will need to acquire new techniques, while reinforcing the collaboration between otorhinolaryngologists and neurosurgeons [49]. However, some techniques can be performed with an articulated arm such as an endoscope holder, which allows an operator to work with two instruments and avoid the congestion related to the presence of two operators (otorhinolaryngologist and neurosurgeon) at the patient’s head.

**Morbidity related to endoscopic surgery**

Endonasal surgery comprises a number of advantages compared to conventional open surgery, particularly the absence of a skin scar, bone flap, and especially the absence of brain retraction in either the frontal or temporal lobe.

However, these techniques are not totally devoid of morbidity. The problem of CSF leak has already been discussed. Other disadvantages are also related to healing of the operative cavity. In a prospective study published in 2010 [35], almost all (98%) patients experienced nasal crusting and/or nasal discharge. Nasal crusting persisted for an average of 101 days. A quality of life study published in 2010 [50], concluded on a globally good quality of life following the operation, particularly in patients operated for the first time via a transsellar approach and without creation of a nasoseptal flap. The patients’ main complaints concerned the presence of nasal crusting, nasal obstruction, postnasal discharge, and sleep disorders. Nasal synchiae, alar sill burn, maxillary nerve hypoesthesia, serous otitis media, taste disturbance, and malodor were reported less frequently. Sinus symptoms can be limited by repeated debridement of the operative cavity performed in the office under local anaesthesia, and by daily nasal irrigation with saline.

**Conclusion**

The development of endoscopic techniques has opened up vast perspectives in the field of skull base surgery. Endonasal surgery provides access to a wide range of lesions in a wide range of sites by using the natural surgical corridor of the nasal cavities.

However, endoscopic endonasal surgery is a relatively recent technique and although certain procedures have been demonstrated to be effective, others have yet to be validated. Particularly in the field of cancer surgery, the follow-up of current series is too short to allow any formal recommendations in favour of endoscopic techniques. Patients should be informed about these limited data and their informed consent should be obtained before the operation.

The importance of collaboration between neurosurgeons and otorhinolaryngologists must be stressed in this type of surgery situated at the crossroads between these two surgical specialties. As with all other new techniques, endoscopic endonasal skull base surgery is associated with a learning curve. Teams wishing to perform this type of surgery should therefore acquire these new techniques in common and jointly develop their skills: their complementarity always constitutes a major advantage when performing four-hand surgical procedures.

**Disclosure of interest**

The authors declare that they have no conflicts of interest concerning this article.

**References**


