Extended endoscopic endonasal approach to the midline skull base: the evolving role of transsphenoidal surgery

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Contents

Abstract

The evolution of the endoscopic endonasal transsphenoidal technique, which was initially reserved only for sellar lesions through the sphenoid sinus cavity, has lead in the last decades to a progressive possibility to access the skull base from the nose. This route allows midline access and visibility to the suprasellar, retrosellar and parasellar space while obviating brain retraction, and makes possible to treat transsphenoidally a variety of relatively small midline skull base and parasellar lesions traditionally approached transcranially.

We report our current knowledge of the endoscopic anatomy of the midline skull base as seen from the endonasal perspective, in order to describe the surgical path and structures whose knowledge is useful during the operation. Besides, we describe the step-by-step surgical technique to access the different compartments, the "dangerous landmarks" to avoid in order to minimize the risks of complications and how to manage them, and our paradigm and techniques for dural and bony reconstruction. Furthermore, we report a brief description of the useful instruments and tools for the extended endoscopic approaches.

Between January 2004 and April 2006 we performed 33 extended endonasal approaches for lesions arising from or involving the sellar region and the surrounding areas. The most representative pathologies of this series were the ten cranioparyngiomas, the six giant adenomas and the five meningiomas; we also used this procedure in three cases of chordomas, three of Rathke's cleft cysts and three of meningo-encephaloceles, one case of optic nerve glioma, one olfactory groove neuroendocrine tumor and one case of fibro-osseous dysplasia.

Tumor removal, as assessed by post-operative MRI, revealed complete removal of the lesion in 2/6 pituitary adenomas, 7/10 craniopharyngiomas, 4/5 meningiomas, 3/3 Rathke's cleft cyst, 3/3 meningo-encephalocele.

Surgical complications have been observed in 3 patients, two with a craniopharyngioma, one with a clival meningioma and one with a recurrent giant pituitary macroadenoma involving the entire left cavernous sinus, who developed a CSF leak and a second operation was necessary in order to review the cranial base reconstruction and seal the leak. One of them developed a bacterial meningitis, which resolved after a cycle of intravenous antibiotic therapy with no permanent neurological deficits. One patient with an intra-suprasellar non-functioning adenoma presented with a generalized epileptic seizure a few hours after the surgical procedure, due to the intraoperative massive CSF loss and consequent presence of intracranial air. We registered one surgical mortality.

In three cases of craniopharyngioma and in one case of meningioma a new permanent diabetes insipidus was observed. One patient developed a sphenoid sinus mycosis, cured with antimycotic therapy. Epistaxis and airway difficulties were never observed.

It is difficult today to define the boundaries and the future limits of the extended approaches because the work is still in progress. Such extended

endoscopic approaches, although at a first glance might be considered something that everyone can do, require an advanced and specialized training.

Keywords: Endoscope; transsphenoidal surgery; extended approach; anatomy; surgical technique; skull base.

Introduction

The base of the skull is amongst the most fascinating and complex anatomical areas, either from the anatomical and surgical perspectives. It can be involved in a variety of lesions, either neoplastic or not and the successful treatment of such pathologies may be extremely difficult to achieve, without paying an high cost in terms of invasiveness, morbidity and mortality, specially for those lesions located in the midline. For most of the lesions of the skull base area, a variety of innovative skull base cranio-facial approaches including anterior, antero-lateral and and postero-lateral routes, have been developed [1, 27, 28, 53, 62–64, 68, 69, 76, 77, 79, 92, 98, 100, 109, 113, 115, 124, 127, 130, 134, 136, 146]. Most large tumors often require combinations of multiple approaches or staged operations, with extensive bone and tissue disruption, which can be aesthetically disfiguring, and a certain degree of neurovascular manipulation, with obvious repercussions on the perioperative morbidity and/or mortality rates, is a prerequisite step of the surgical action.

The evolution of surgical techniques has lead in the last decades to a progressive reduction of the invasiveness of these approaches, namely through the transcranial routes, but the possibility to access the skull base from the nose was initially reserved only for sellar lesions through the sphenoid sinus cavity. It was Weiss in 1987 [149] that termed and originally described the **extended transsphenoidal approach**, intending a transsphenoidal approach with removal of additional bone along the tuberculum sellae and the posterior planum sphenoidale between the optic canals, with subsequent opening of the dura mater above the diaphragma sellae. This route allows midline access and visibility to the suprasellar space while obviating brain retraction, and makes possible to treat transsphenoidally small midline suprasellar lesions traditionally approached transcranially, namely tuberculum sellae meningiomas and craniopharyngiomas. Initially, such operations were done with microsurgical technique [91, 97, 110, 149].

Perhaps, it has been the fundamental contribute brought by the endoscope in transsphenoidal surgery, together with the progress in diagnostic imaging techniques and the intraoperative neuronavigation systems, that have boosted the development of the extension of the transsphenoidal approach to the entire midline skull base. Furthermore, because of the increased visualization offered by the endoscope, a variety of modifications of the standard transsphenoidal approach have been described, which have created new surgical routes targeted for the extrasellar compartment from the anterior cranial base to the craniocervical junction [2, 3, 16, 17, 25, 31, 33, 38, 40, 41, 43, 45, 48, 54, 56, 58, 85, 86, 88, 91, 97, 106] As a matter of facts, endoscopy has caused a renewal of the interest for anatomic studies, which are essential to the comprehension of the approach itself, and has contributed to the more contemporary knowledge of the possibilities of the transsphenoidal approach also on clinical settings [3, 14, 25, 33, 40, 41, 78, 80, 82–84, 102, 107, 121, 122, 133, 140].

Such considerations give an idea of the extended endoscopic endonasal route as a versatile approach [40] that offers the possibility to expose the entire midline skull base from below, with the possibility to pass through a less noble structure (nasal cavity) in order to reach a more noble one (the brain with its neurovascular structures). Indeed, cases of suprasellar, retroclival, and intracavernous lesions treated by means of the transsphenoidal technique, either fully endoscopic or endo-microscopically assisted procedures are now routinely done in Centers dedicated to such type of surgery.

Endoscopic anatomy of the midline skull base: the endonasal perspective

According to the surgical view, the anatomy of the midline skull base can be divided in three areas:

1) the midline anterior skull base: from the frontal sinus to the posterior ethmoidal artery;
2) the middle skull base: the sphenoid sinus cavity;
3) the posterior skull base: from the dorsum sellae to the cranio-vertebral junction.

The anterior skull base: from the frontal sinus to the posterior ethmoidal artery

From the endonasal point of view the midline anterior skull base corresponds to the roof of the nasal cavities. After the removal of the anterior and posterior ethmoid cells and of the superior part of the septum (lamina perpendicularis), the anterior skull base appears as a rectangular area limited laterally by the medial surfaces of the orbital walls (lamina papyracea), posteriorly by the planum sphenoidale and anteriorly by the two frontal recesses (see Fig. 1a, b). This area is divided into two simmetrical parts by the lamina perpendicularis of the ethmoid bone. Each part is formed by the lamina cribrosa medially and ethmoid labyrinth laterally. The lamina cribrosa is a very thin osseous membrane crossed by olfactory nerves fibres, while the ethmoid labyrinth is formed by the anterior and posterior ethmoidal complexes. The anterior ethmoidal complex is constituted by the bullar and the suprabullar recesses and is separated from the posterior ethmoidal complex by the basal lamella of the middle turbinate [143]. The arterial supply of the dura mater of the ethmoidal planum

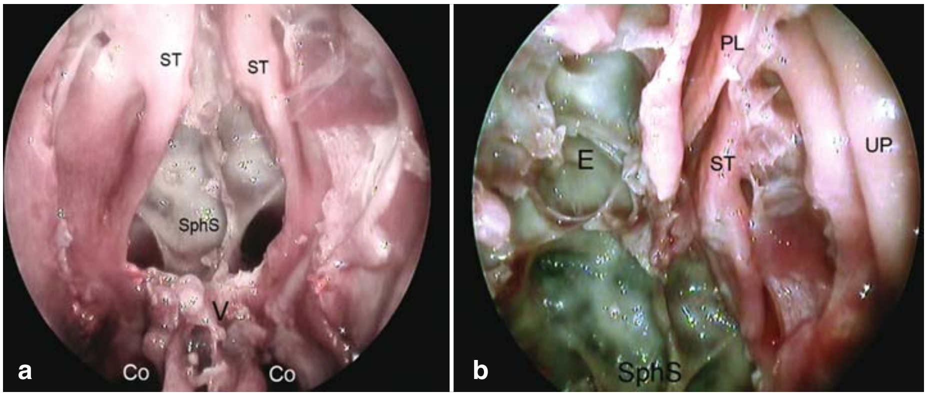

Fig. 1. Endoscopic endonasal anatomy of the anterior midline skull base. a) The superior portion of the nasal septum, the middle turbinate on both sides and the anterior wall of the sphenoid sinus have been removed. The superior turbinate and the ethmoid complex of both sides are visible. b) On the right side the anterior and posterior ethmoid cells have been opened. *SphS* Sphenoid sinus; *V* vomer; *Co* choana; *ST* superior turbinate; *E* ethmoid cells; *PL* perpendicularis lamina; *UP* uncinate process

is ensured by the anterior ethmoidal artery (AEA) and the posterior ethmoidal artery (PEA), that are branches of the oftalmic artery. These vessels send many small branches to the cribriform plate where they anastomize with the nasal branches of the sphenopalatine artery.

The AEA, after branching off, passes in the medial part of the optic nerve and in the lateral part of the superior oblique and medial rectus muscles to reach the anterior ethmoidal foramen at the lamina papyracea; it initially curves posteriorly and then anteriorly, in an anteromedial direction, running into the anterior ethmoidal canal (AEC) to reach the cribriform plate [47, 114, 150]. For the identification of the anterior ethmoidal artery (AEA) it is essential to expose the frontal recess. The frontal recess is constituted by the anterior part of the middle turbinate medially, by the lamina papyracea laterally and by the agger nasi cell anteriorly. The posterior ethmoidal artery, after its origin from the ophthalmic artery, runs between the rectus superior and the superior oblique muscle, then emerges from the orbit to enter the posterior ethmoidal canal (PEC) which courses horizontally the ethmoidal roof. It is useful to identify the carotid and optic protuberances and the opto-carotid recess located on the posterior wall of the sphenoid sinus in order to expose the PEA (see Fig. 2a, b). The posterior ethmoidal artery runs only few millimeters anteriorly to the roof of the sphenoid sinus cavity. Therefore its course has to be kept in mind during the transplanum approach, in order to avoid its accidental injury. Opening the dura of the anterior cranial fossa the olfactory nerves and the basal surface of the frontal lobes are visualized.

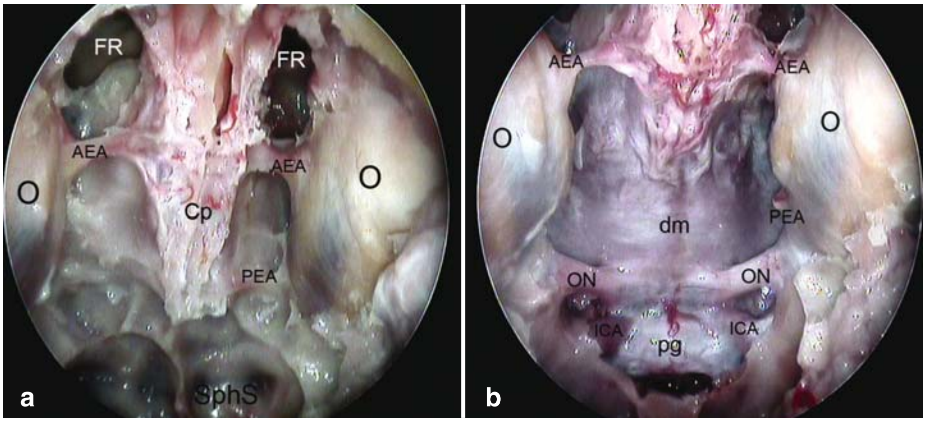

Fig. 2. Endoscopic endonasal anatomy of the anterior midline skull base. a) The anterior and posterior ethmoidal labyrinth on both side has been removed in order to visualize the anterior and posterior ethmoidal arteries in their bone canals. b) Panoramic view after the bilateral ethmoidectomy showing the dura mater of the anterior midline skull base from the frontal sinus till the sellar region. *FR* Frontal recess; *AEA* anterior ethmoidal artery; *PEA* posterior ethmoidal artery; *O* orbit; *Cp* cribiform plate; *ICA* internal carotid artery; *ON* optic nerve; *dm* dura mater; *pg* pituitary gland

The middle skull base: the sphenoid sinus cavity [24]

Seen from the nasal cavity, the middle skull base corresponds to the posterior and lateral walls of the sphenoid sinus, where a series of protuberances and depressions are recognizable. The sellar floor is at the center, the spheno-ethmoid planum above it and the clival indentation below; lateral to the sellar floor the bony prominences of the intracavernous carotid artery (ICA) and the optic nerve can be seen and, between them, the lateral opto-carotid recess, moulded by the pneumatization of the optic strut of the anterior clinoid process (see Fig. 3a, b) [148]. The superior border of the lateral opto-carotid recess is covered by a thickening of the dura and periosteum which forms the distal dural ring, separating the optic nerve from the clinoidal segment of the internal carotid artery. The inferior border of the lateral opto-carotid recess is covered by a tickening of the dura and periosteum, which forms the proximal dural ring, which covers the third cranial nerve, the upper one inside the superior orbital fissure. Although rarely visible in the cavity of the sphenoid sinus, it is important to define the position of the medial opto-carotid recess since its removal on both sides significantly increases the surgical exposure over the suprasellar area. It corresponds intracranially to the medial clinoid process, which is present in about 50% of cases. The medial opto-carotid recess can be identified using as landmarks the lateral opto-carotid recess (see Fig. 4a–c).

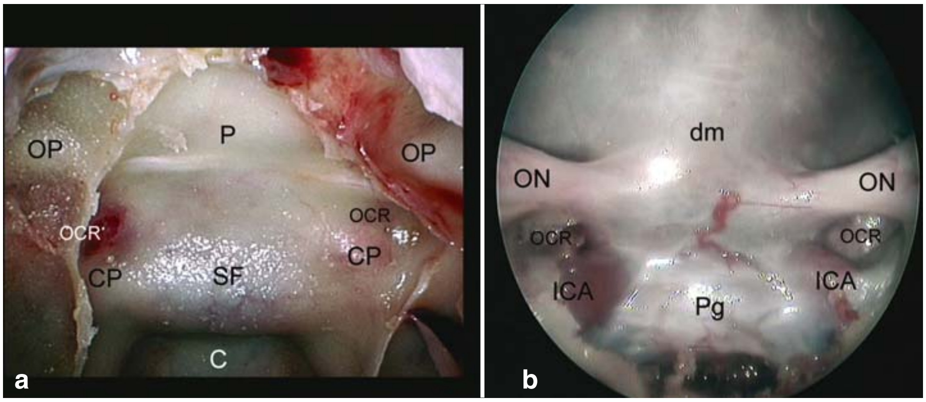

Fig. 3. Endoscopic endonasal anatomy of the middle skull base. a) The sphenoid septa have been removed allowing the identification of all the bone landmarks on the posterior wall of the sphenoid sinus. b) The posterior wall of the sphenoid sinus has been completely drilled out in order to expose the underlying anatomical structures. *P* Planum sphenoidale; *OP* optic protuberance; *OCR* opto-carotid recess; *CP* carotid protuberance; *SF* sellar floor; *C* clivus; *ON* optic nerve; *ICA* internal carotid artery; *dm* dura mater of the planum sphenoidale; *Pg* pituitary gland

Proceeding laterally other bony anatomical landmarks can be recognized, such as the cavernous sinus apex, the trigeminal maxillary and the trigeminal mandibulary protuberances, which is seen only in a well pneumatized sphenoid sinus. These bony bulges limit two main depressions, the first between the cavernous sinus apex and V2 protuberances and the other between V2 and V3 protuberances [3]. On the fllor of the sphenoid sinus cavity, specially when it is well pneumatized, it is possible to recognize the protuberance of the vidian nerve passing through the middle cranial fossa and foramen lacerum and entering the pterygopalatine fossa through the pterygoid canal, to reach the pterygopalatine ganglion.

Removing the bone and the dura over the sella, the tuberculum sellae and the posterior part of the planum sphenoidale it is possible to explore the suprasellar region. It has been divided in four areas using two ideal planes, one passing trough the inferior surface of the chiasm and the mammilary bodies, and one passing trough the posterior edge of chiasm and the dorsum sellae: supra-chiasmatic, sub-chiasmatic, retrosellar and ventricular (see Fig. 5).

In the **supra-chiasmatic area** the anterior margin of the chiasm and the medial portion of the optic nerves in the chiasmatic cistern, as well as the A_1 and A_2 segments and the anterior communicating artery in the lamina terminalis cistern are visualized (see Fig. 6a).

In the **sub-chiasmatic area** the first structure encountered is the pituitary stalk. The superior hypophyseal arteries and the branches for the inferior surface of the optic chiasm and nerves are visible (see Fig. 6a).

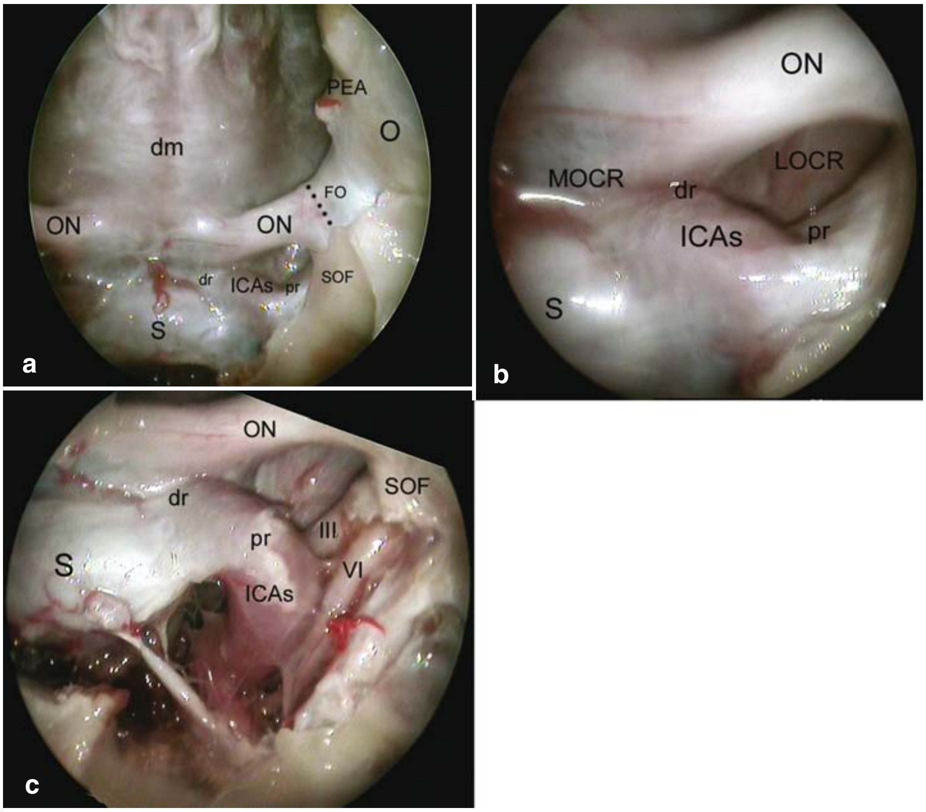

Fig. 4. Endoscopic endonasal anatomy of the middle skull base. a) After removal of the optic and carotid bone protuberances, it is possible to recognize the periostal dural layer covering the neurovascular structures. b) A close-up view of the lateral and medial opto-carotid recess. c) After opening of the cavernous sinus, the third and sixth cranial nerves converging towards the superior orbital fissure are visible. dm Dura mater; *PEA* posterior ethmoidal artery; *ON* optic nerve; *O* orbit; *S* sella; *ICAs* parasellar segment of the internal carotid artery; *dr* distal ring; *pr* proximal ring; *MOCR* medial opto-carotid recess; *LOCR* lateral opto-carotid recess; *III* oculomotor nerve; *VI* abducent nerve; *SOF* superior orbital fissure

The **retrosellar area** is reached passing between the pituitary stalk and the internal carotid artery, above the dorsum sellae. The upper third of the basilar artery, the pons, the superior cerebellar arteries, the oculomotor nerve and the posterior cerebral arteries are recognized. The mammillary bodies with the floor of the third ventricle are also visible (see Fig. 6b).

The opening of the floor of the third ventricle at the level of the tuber cinereum allows to explore the **ventricular area**. The lateral walls of the ventricle, formed by the medial portion of the talami, the interthalamic commissure, as well as the foramens of Monro are visible. On the posterior wall of

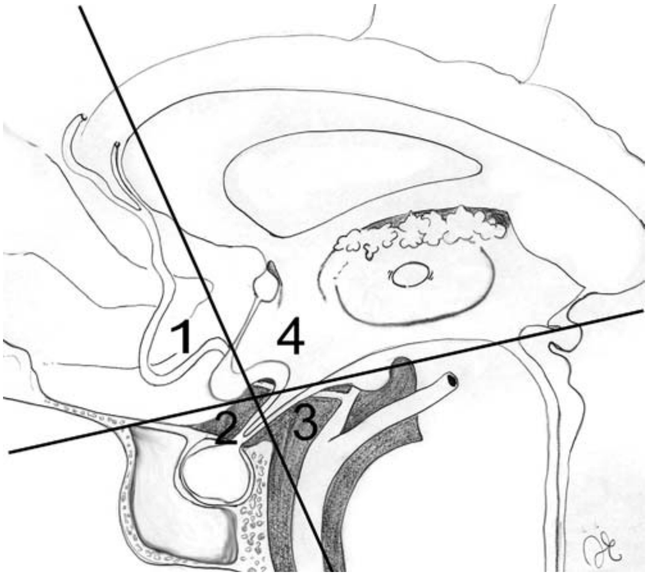

Fig. 5. Endoscopic endonasal anatomy of the middle skull base. Schematic drawing showing the areas explorable with the endoscope through the transtuberculum-transplanum sphenoidale approach. They have been divided in: *1* suprachiasmatic; *2* infrachiasmatic; *3* retrosellar; *4* intraventricular

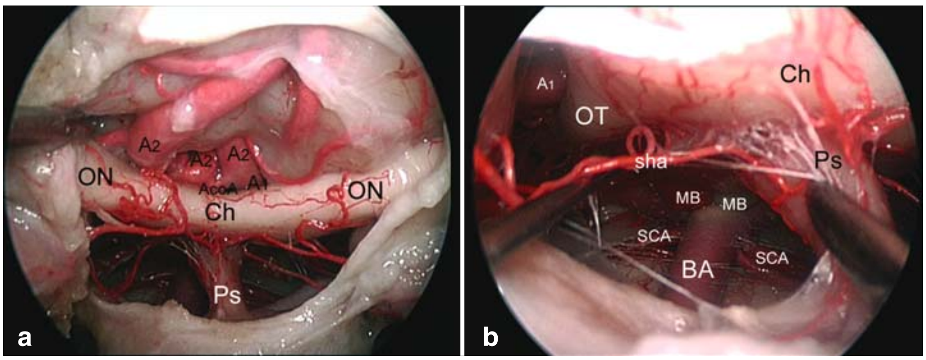

Fig. 6. Endoscopic endonasal anatomy of the middle skull base (intradural exploration). a) Endoscopic endonasal view of the suprachiasmatic and subchiasmatic areas. b) Endoscopic endonasal view of the retrosellar area. *ON* Optic nerve; *Ch* chiasm; *ps* pituitary stalk; *A1* anterior cerebral artery; *AcoA* anterior communicating artery; *A2* anterior cerebral artery; *MB* mammilary body; *sha* superior hypophyseal artery; *OT* optic tract; *SCA* superior cerebellar artery; *BA* basilar artery

the ventricle, it is possible to recognize the pineal and suprapineal recesses, the posterior commissure, the habenular commissure, the habenular trigona and the beginning of the aqueduct (see Fig. 7a–c).

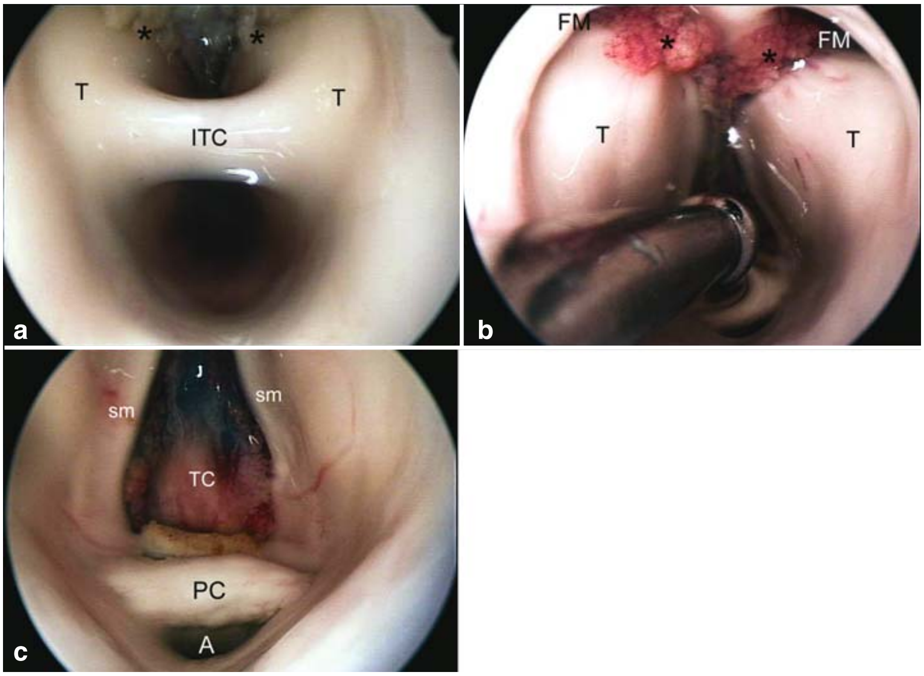

Fig. 7. Endoscopic endonasal view of the cavity of the III ventricle. a) Identification of the interthalamic commissure. b) Passing with the endoscope above the interthalamic adhesion, both the foramens of Monro and the choroids plexuses are visible. c) Passing below the interthalamic adhesion, the posterior portion of the third ventricle becomes visible. *T* Thalamus; *ICT* interthalamic commisure; * choroid plexus; *FM* foramen of Monro; *TC* tela choroidea; *PC* posterior commisure; *A* mesencephalic acqueduct; ** striae medullaris

The removal of the bone covering the lateral wall of the sphenoid sinus and the carotid protuberance permits the exposure of the neurovascular structures that form the anterior part of the cavernous sinus. After removing the fibrous trabecular structure of the medial wall of the cavernous sinus, the C-shaped parasellar segment of the internal carotid artery is immediately seen.

Displacing laterally the ICA, the meningohypophyseal artery and its branches, as well as the proximal portion of the oculomotor and trochlear nerves, can be visualized inside the C-shaped tract of the ICA.

Pushing medially the ICA it is possible to observe the lateral wall of the cavernous sinus from its interior surface. The origin of the infero-lateral trunk and its branches are detected. The oculomotor, the abducent nerves and the maxillary branch of the trigeminal nerve (V2) lie on an inner plane, compared with the trochlear nerve and the ophthalmic nerve (V1), thus the oculomotor nerve covers the trochelar nerve while the six nerve partially covers the first branch of the trigeminal nerve (see Fig. 8a, b). The oculomotor nerve passes at the level of the parasellar carotid artery, where it is usually joined by sympathetic

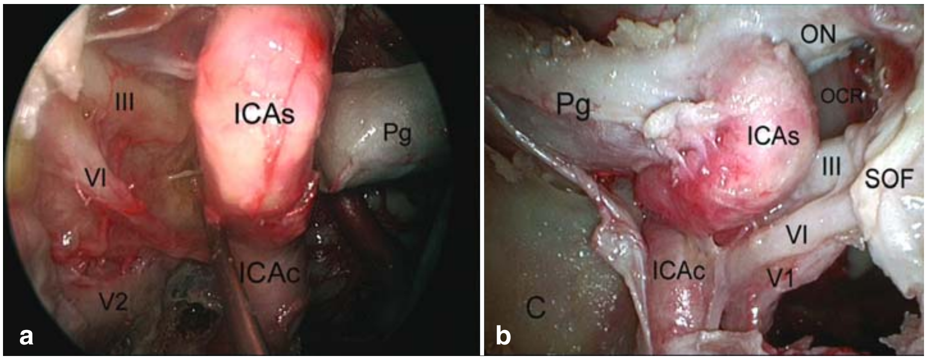

Fig. 8. Endoscopic endonasal anatomy of the cavernous sinus. a) Displacing medially the internal carotid artery, the third, the sixth and the maxillary branch of the trigeminal nerve are recognizable. b) After removal of the lateral wall of the cavernous sinus, the ophthalmic branch of the trigeminal nerve is also visible. *Pg* Pituitary gland; *OCR* opto-carotid recess; *III* oculomotor nerve; *VI* abducent nerve; *V1* ophthalmic branch of the trigeminal nerve; *ICAs* parasellar segment of the internal carotid artery; *ICAc* paraclival segment of the internal carotid artery; *ON* optic nerve; *C* clivus

fibers from the adventitia of ICA. The trochlear nerve lies parallel and just inferior to the oculomotor nerve. The abducens nerve crosses the ICA at the level of the rostral portion of the paraclival segment. The III, the IV and the ophthalmic nerve run upward to reach the superior orbital fissure, while the maxillary nerve runs caudally to reach the foramen rotundum. The oculomotor nerve superiorly, and the abducens nerve inferiorly limit a triangular area with the base represented by the lateral loop of the ICA. The surface of this area contains the throclear nerve and a part of V1. The abducens nerve superiorly and V2 inferiorly define a quadrangular area laterally delimited by the bone of the lateral wall of sphenoid sinus, from the superior orbital fissure to the foramen rotundum, and medially by the ICA. The ophthalmic branch of the trigeminal nerve and the artery of the inferior cavernous sinus run in this area. In case of a well pneumatized sphenoid sinus an inferior quadrangular area is identificable. Superiorly is delimited by V2 and inferiorly by the vidian nerve. The lesser base is formed by the intrapetrous segment and the caudal portion of the vertical tract of the ICA; the anterior edge is formed by the bone of the lateral wall of the sphenoid sinus from the foramen rotundum to the pterygoid canal [23].

The posterior skull base: from the dorsum sellae to the cranio-vertebral junction

From an inferior route, the midline posterior cranial fossa is represented by the anterior surface of the clivus, from the dorsum sellae to the cranio-vertebral junction. The clivus is divided by the inferior wall of the sphenoid sinus in an

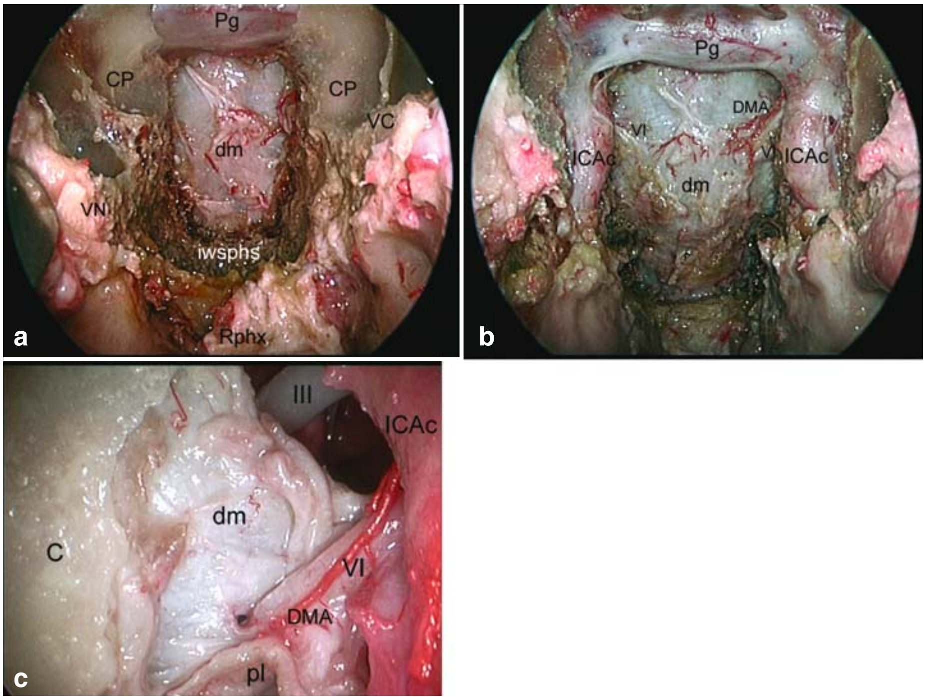

Fig. 9. Endoscopic endonasal anatomy of the clival area. a) The bone of the clivus and of the inferior wall of the sphenoid sinus have been removed up to identify the Vidian nerves. b) After complete removal of the bony protuberance of the intracavernous carotid arteries, the abducent nerve and its relationships with the dorsal meningeal artery are visible. c) Note the abducent nerve passing behind the the paraclival segment of the intracavernous carotid artery. *Pg* Pituitary gland; *CP* carotid protuberance; *ICAc* paraclival tract of the intracavernous carotid artery; *VN* Vidian nerve; *VC* vidian canal; *Rphx* rhinopharynx; *dm* dura mater; *DMA* dorsal meningeal artery; *III* oculomotor nerve; *VI* abducent nerve; *pl* periostial layer

upper part (sphenoid portion) and in a lower part (rhino-pharyngeal portion). Laterally on the sphenoid portion of the clivus the carotid protuberances are visible. After removal of the bone of the upper part of the clivus the periostium-dural layer is exposed; the opening of the carotid protuberance permits to identify the sixth cranial nerve, which passes together with the dorsal meningeal artery just medially to the paraclival carotid artery, thus representing the real lateral limit of the approach at this level (see Fig. 9a–c). After the opening of the dura, the basilar artery and its branches, as well as the upper cranial nerves, are well seen along their courses in the posterior cranial fossa (see Fig. 10a, b).

Extending the bone removal to the inferior wall of the sphenoid sinus the rhinopharynx is exposed. The lower third of the clivus is removed and both the *foramina lacera* are identified, representing them the lateral limit of the approach at this level. It is possible to further enlarge this opening by removing the

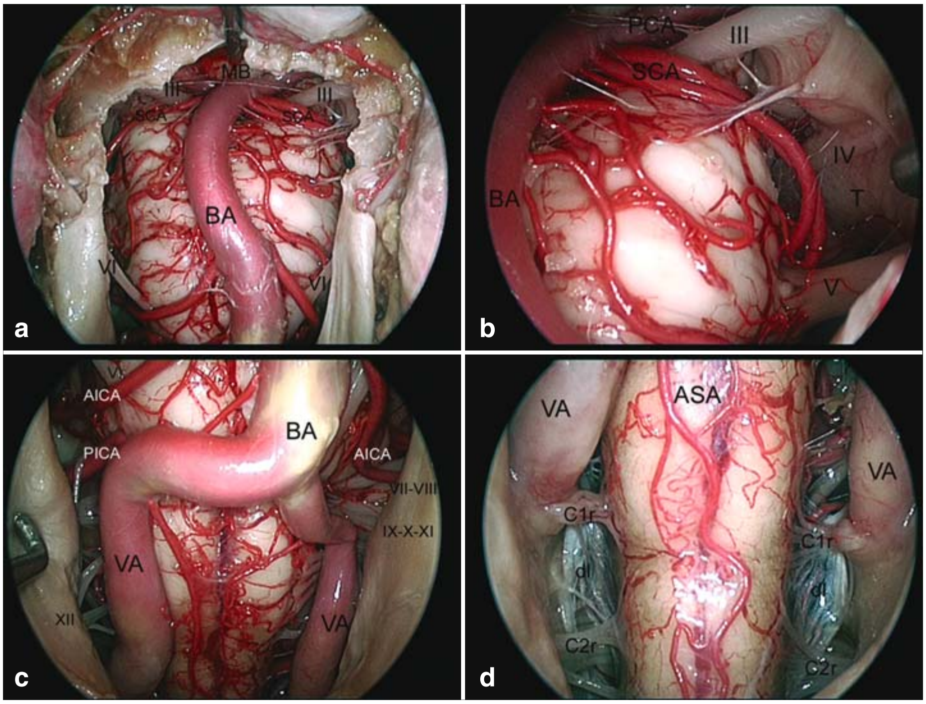

Fig. 10. Endoscopic endonasal anatomy of the clivus and cranio-vertebral junction (intradural exploration). a) After the opening of the dura, the basilar artery and the ventral surface of the brain stem become visible. b) With the endoscope in close-up view it is possible to see the entry zones of the oculomotor and the trigeminal nerves. c) The vertebral arteries, the spino-medullary junction and the lower cranial nerves are exposed. d) The entrance of the vertebral arteries in the vertebral canal as well as the ventral rootlets of the first two cervical nerves and the dentate ligaments, are visible. *SCA* Superior cerebellar artery; *BA* basilar artery; *III* oculomotor nerve; *IV* trochlear nerve; *T* tentorium; *V* trigeminal nerve; *VI* abducent nerve; *XII* hypoglossal nerve; *IX–XI* glossopharyngeal, vagus and accessory nerves; *VII*, *VIII*: acoustic-facial boundle; *PICA* posterior inferior cerebellar artery; *AICA* anterior inferior cerebellar artery; *VA* vertebral artery; *ASA* anterior spinal artery; *dm* dura mater; *C1r* ventral rootlets of the first cervical nerve; *C2r* ventral rootlets of the second cervical nerve; *dl* dentate ligament

anterior third of the occipital condyles, without entering in the hypoglossal canal, which is located at the junction of the anterior and middle third of each occipital condyle. Moreover the articular surface of the condyle is located on its lateral portion, so that the removal of its inner third, through an anterior route, does not involve the articular junction. The mucosa of the rhinopharynx is removed and the atlanto-occipital membrane, the longus capitis and colli muscles, the atlas and axis are exposed (see Fig. 11a, b). The anterior arch of the atlas is removed and the dens is exposed (see Fig. 11c). Using the microdrill the dens is thinned; it is then separated from the apical and alar ligamens and

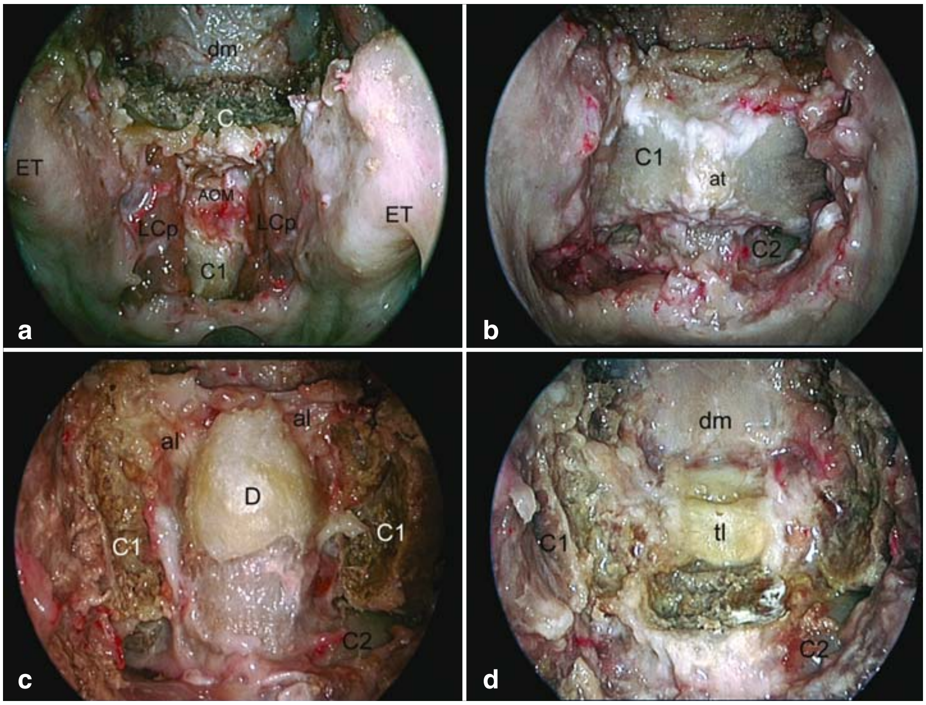

Fig. 11. Endoscopic endonasal anatomy of the cranio-vertebral junction. a, b) The mucosa of the rhinopharynx has been removed and the longus capitis and longus colli muscles have been elevated in order to expose the cranio-vertebral junction. c) The anterior arch of the atlas has been drilled out and the dens has been exposed. d) After removal of the dens, the transverse ligament is visible. *dm* Dura mater; *C* clivus; *LCp* longus capitis muscle; *AOM* anterior atlanto-occipital membrane; *C1* atlas; *at* anterior tubercle; *ET* Eustachian tube; *C2* axis; *tl* transverse ligament; *al* alar ligaments

finally dissected from the transverse ligament and removed (see Fig. 11d). The vertebral arteries can be explored from their dural entrance up to their confluence in the basilar artery. The posterior inferior cerebellar artery (PICA) and the anterior ventral spinal artery are also visible. Above and behind the vertebral artery the lower cranial nerves and the acoustic-facial boundle (VII–VIII), with the antero inferior cerebellar artery (AICA), are visible. The rootlets of the hypoglossal nerve as well as the ventral rootlets of C1 and C2, and the dentate ligament between them can be identified (see Fig. 10c, d).

Instruments and tools for extended approaches

Extended endoscopic endonasal approaches to the skull base have been accompanied and facilitated by the design and development of dedicated endonasal instruments and tools, some of them following prior studies on the endoscopic transsphenoidal approach for sellar lesions [9, 12, 29].

As already noted, the extended endoscopic operations basically use the endonasal route to access the entire midline skull base. Such a corridor is more restricted when compared with the "open" approaches and, therefore, the handling of the instruments is not always easy, specially when trying to control bleeding. As a matter of fact, the control of bleeding, specially when arterial, may constitute one of the most cumbersome problems of endoscopic surgery. Even though monopolar coagulation can be easily employed inside the nose, its extensive use is not recommended because of the potential injury of neural fibers of the olfactory nerve in the posterior part of the nasal cavities.

Furthermore, monopolar coagulation must be avoided close to major neurovascular structures, such as on the posterior wall of the sphenoid sinus, in the intradural space or in proximity to nerve or vascular bony protuberances within the sphenoid sinus. Some endoscopic monopolars are combined with a suction cannula to aspirate the smoke during coagulation, which maintains a clear surgical field. For such reasons, bipolar coagulation should be preferred. Although the use through the nose of the classic microsurgical bipolar forceps is possible, their maneuverability is not always easy or secure due to their shape. Consequently, different endonasal bipolar forceps have been designed, with various diameters and lengths, which have proven to be quite effective in bipolar control of bleeding. The bipolar forceps for endoscopic surgery need to have some special features: i) they should have a shape to be easily introduced and manoeuvred in the nasal cavity; ii) the tips of the forceps have to be adequately isolated. For the purposes of the extended endonasal endoscopic surgery, the bipolar has the shape of forceps with ring handle like scissors. The movements of the handle causes the tips to open and close and, eventually, to coagulate. Furthermore, new coagulating instruments, either monopolar and bipolar, based on radiofrequency waves have been proposed in such types of operations (Ellman Innovations, Oceanside, NY, USA): they have the advantages that the spatial heat dispersion is minimal, with consequent minimal risk of heating injury to the neurovascular structures. Besides, the radiofrequency bipolar forceps do not need to be used with irrigation or to be cleaned every time.

Endoscopic endonasal skull base surgery demands the use of special instruments and devices that have proven to be quite helpful for the effectiveness and safety of the procedure, even though they are not absolutely needed.

Image guided neuronavigation systems are very useful for intraoperative identification of the limits of the lesion and of the bony, vascular and nervous structures, especially if they are encased by the tumor [46, 101, 117, 129]. In some select cases, the classic landmarks for endoscopic transsphenoidal surgery (sellar floor, clival indentation, carotid and optic nerve protuberances, optico-carotid recess) are not easily identifiable and neuronavigation can help to maintain the surgeon's orientation even in the presence of distorted anatomy. However, the use of such devices requires the head of the patient to be fixed in the three-pin skeletal fixation headrest in order to render the head of the patient fixed with the reference system. Some authors use the three-pin headrest not fixed to the surgical table but the head is actually put in the horseshoe headrest [45, 48]. The neuronavigation systems and the panoramic view provided by the endoscope also make it possible to do without the use of fluoroscopy, thus avoiding unnecessary radiation exposure to the patient and the surgical team.

High-speed low-profile drills may be very helpful for the opening the bony structures to gain access to the dural space [45, 48]. They are specifically designed for endonasal use and have some special characteristics: they are low-profile and also long enough but not too bulky, so they can be easily used together with the endoscope (The Anspach Efforts, Inc., Palm Beach Gardens, Florida, USA). The combined use of such drills and endonasal bony rongeurs have proven to be effective and time-saving during the extended approaches to the skull base, especially for access to the suprasellar or retroclival regions. It is important to find a good balance between the length of the tip and stability during fine drilling, as a too long tip may dangerously vibrate.

Prior to opening the dura mater and whenever the surgeon thinks it is appropriate (especially while working very close to vascular structures), it is of utmost importance to use the microDoppler probe to insonate the major arteries [4, 45, 48, 151]. The use of such a device is particularly useful while operating inside the cavernous sinus, in the retroclival prepontine area or in the suprasellar space.

Endoscopic endonasal techniques

Basic steps for extended endonasal transsphenoidal approaches

The procedure goes through the same basic steps of a standard transsphenoidal operation – i.e., vision of the surgical target areas by means of a rigid diagnostic endoscope (Karl Storz Endoscopy, Tuttlingen, Germany) and their exposure, followed by management and removal of the lesion and, finally, reconstruction of the approach route. All the extended endoscopic endonasal procedures have been performed in a fully integrated operating room (Karl Storz OR1^{TM}), centrally monitored and controlled, in which surgical processes and routine work are simultaneously streamlined and simplified. Such operating room is dedicated for minimally invasive procedures.

According with the concepts outlined by Perneczky [120], the approach could be considered a "key-hole" procedure, with a "door" – the sphenoid sinus – a "window" to be open on the skull base and different "corridors" to the different "rooms" – the various perisellar compartments.

In contrast to traditional transsphenoidal approach to the sellar region, where a horse-shoe headrest is used, in extended approaches a rigid three-pin head fixation is preferred because an image-guided system is required.

The head is turned 10–15° on the horizontal plane, towards the surgeon, who is on the patient's right side and in front of him and extended for about 10–15° for lesions located in the suprasellar area or on the cribiform plate and slightly flexed for those lesions located in the clival area. These changes of the head position are necessary to allow an optimal position of the endoscope during the surgical procedure: not too close to the thorax, nor perpendicular to the patient's head. The surgical corridor required for the extended approaches is wider in respect to that of the standard approach [11, 15, 39]. To increase the working space and the manoeuvrability of the instruments it is necessary: i) to remove the middle turbinate on one side; ii) tolateralize the middle turbinate in the other nostril; and iii) to remove the posterior portion of the nasal septum (see Fig. 12a, b). These surgical maneuvers allow the use of both nostrils, so that two or three instruments plus the endoscope can be inserted.

The procedure starts with the removal of the middle turbinate, which represents an important step of the procedure, since it allows the creation of a larger corridor through one nostril, thus permitting the easy introduction of the endoscope and of one instrument. Usually the right middle turbinate is removed. The areas just above the head of the middle turbinate and its tail are coagulated. The head of the middle turbinate is cut with nasal scissors and pushed downward in order to expose its tail. After completing hemostasis around the tail of the turbinate, the tail is cut and the turbinate is removed.

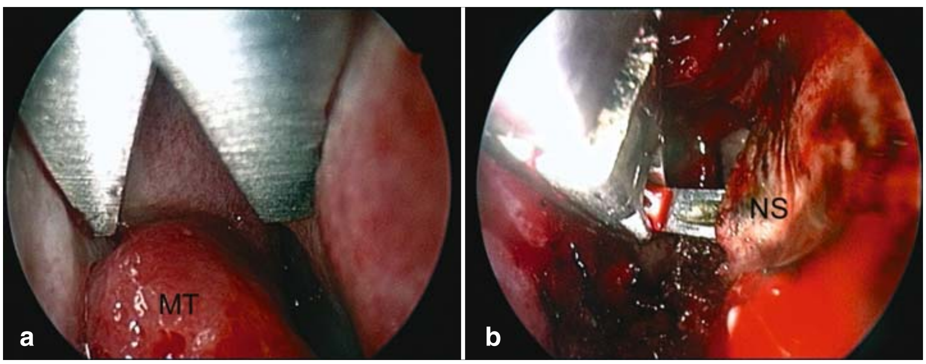

Fig. 12. Basic concepts for extended approaches. a) Right middle turbinectomy; b) removal of the posterior portion of the nasal septum with a retrograde bone punch. *NS* Nasal septum; *MT* middle turbinate

Such technique has been performed according with the guidelines of the Pittsburgh's group [86].

With a retrograde bone punch, the posterior nasal septum is then removed to a variable extent and the mucosal edges are accurately coagulated with the bipolar forceps. In this way, the nasal septum does not blur the endoscopic view when other instruments are inserted through the other nostril, this being a binostril technique. In those cases in which a wide osteo-dural opening is necessary over the planum or the clivus a mucopericondrial flap harvested from the nasal septum can be realized to render more effective the reconstruction at the end of the procedure. The flap is created cutting the septal mucosa along the inferior edge of the septum from the roof of the choana to the cartilaginous portion and superiorly at the level of the rostral portion of the middle turbinate. Then the mucoperichondrium flap is dissected from the septal bone and pedicted around the sphenopalatine foramen. During the operation, the flap is located in the choana and at the end of the procedure is used to cover the posterior wall of the sphenoid sinus, to support the reconstruction materials [66].

The middle turbinate of the contralateral nostril is pushed laterally with an elevator allowing a binasal route for the instruments. Up to this point, the surgical procedure is usually performed by one surgeon who holds the endoscope with one hand and one instrument with the other. From now on, the endoscope is held by the assistant and the surgeon can use both his hands [22]. The two nostril approach requires good collaboration between of two surgeons as if they were running a rally car race: one holds the endoscope and can be considered a sort of "navigator"; the second, the "pilot", handles two surgical instruments inside the surgical field, as in the traditional microsurgical technique. The "navigator" "dynamically" uses the endoscope during the surgical procedure. He is responsible of the visual control of the instruments, which constantly remain under direct endoscopic view. The endoscope follows the in-and-out movements of the instruments, so minimizing the risks of injury to the neurovascular structures, The other member of the team, the "pilot" surgeon, is free from holding the endoscope and can use two instruments in the operative field. Otherwise the first surgeon holds the endoscope in the non dominant hand and an instrument in the dominant hand, while the second surgeon helps with suction and other tools. In distinction to the microsurgical technique, where the microscope remains outside and the increased magnification narrows the visual field, in this endoscopic technique the "pilot" and the "navigator" continuously pass between the close-up view, as during the dissecting manoeuvres, and a panoramic view of the neurovascular structures.

The anterior sphenoidotomy is performed starting with the coagulation of the spheno-ethmoid recess 5 mm above the choana up to the sphenoid ostium. Using the microdrill with diamond burr the entire anterior wall of the sphenoid sinus is removed. The sphenoidotomy is enlarged more than in the standard approach, especially in lateral and superior direction where bony spurs are flattened in order to create an adequate space for the endoscope during the deeper steps of the procedure. All the septa inside the sphenoid sinus are removed including those attached on the bony protuberances and depressions on the posterior wall of the sphenoid sinus cavity.

The transtuberculum transplanum approach to the suprasellar area

Traditionally surgical approaches for tumors located in the suprasellar region are transcranial and the most favoured are the pterional and the subfrontal routes. Although these procedures are well standardized and widely utilized, several authors have proposed different minicraniotomical approaches to reach the suprasellar area [5, 18, 42, 52, 63, 76, 125], and, even with these, there is the need for a certain degree of brain retraction. The transsphenoidal approach has been widely adopted for the surgical treatment of intrasellar and intra-suprasellar infradiaphragmatic lesions. However some Authors [52, 73, 103] have described successful transsphenoidal removal of suprasellar/supradiaphragmatic lesions. In these cases the access to the suprasellar area is obtained, after the resection of the intrasellar component of the tumor, through a wide opening of the diaphagma sellae (trans-sellar transdiaphragmatic approach). More recently some Authors [17, 31, 33, 40, 41, 45, 57, 82, 85, 91, 95, 97, 102, 105, 110, 149] have reported the successful removal of suprasellar/supradiaphragmatic lesions through a modified transsphenoidal microsurgical approach, the so-called *transsphenoidal transtuberculum approach*. This technique provides a direct access to the supradiaphragmatic space, allowing sufficient exposure for the removal of supradiaphragmatic tumors, regardless of the sellar size (even a not enlarged sella), and preserving normal pituitary tissue and function. This approach permits a direct view of the neurovascular structures of the suprasellar region lesion without any brain retraction.

Surgical procedure

After the preliminary steps for extended transsphenoidal approaches have been performed, the bone removal over the sella starts with the drilling of the tuberculum sellae (see Fig. 13a) which, inside the sphenoid sinus cavity, corresponds to the angle formed by the planum sphenoidale with the sellar floor. The drilling is then extended bilaterally, towards both the medial opto-carotid recesses. The upper half of the sella is removed up to reach the superior intercavernous sinus. A Kerrison's rongeur is used to complete the bone removal from the planum (see Fig. 13b). The extension of the bone removal depends on the size of the lesion and is performed under the control of neuronavigator. Above the opto-carotid recess, the extension of the bone opening

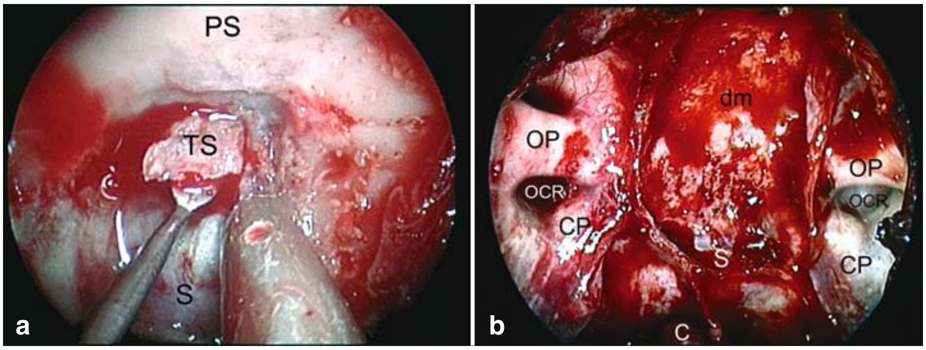

Fig. 13. Extended approach to the planum sphenoidale. a) Isolation and removal of the tuberculum sellae. b) Panoramic view after the bone removal. *PS* Planum sphenoidale; *TS* tuberculum sellae; *S* sella turcica; *OP* optic protuberance; *OCR* opto-carotid recess; *CP* carotid protuberance; *dm* dura mater; *C* clivus

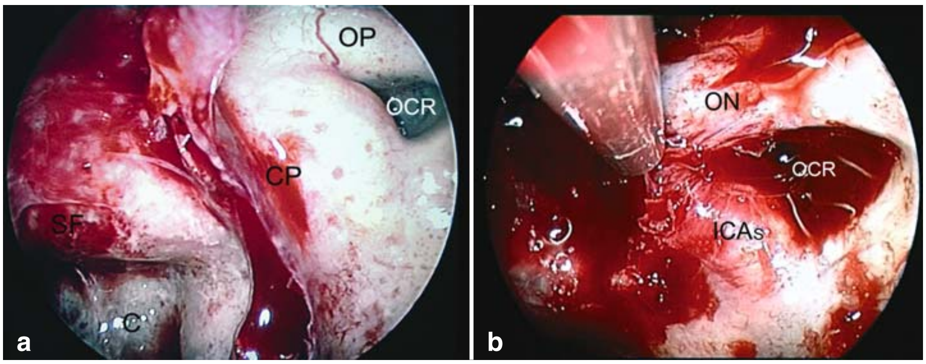

Fig. 14. Extended approach to the planum sphenoidale. a, b) The medial opto-carotid recess, pointed by the suction cannula in figure; b represents the lateral limit of the bone drilling. *SF* Sella turcica; *OP* optic protuberance; *OCR* opto-carotid recess; *CP* carotid protuberance; *C* clivus; *ICAs* parasellar segment of the internal carotid artery; *ON* optic nerve

is limited laterally by the protuberances of the optic nerves, which diverge towards the optic canal (see Fig. 14a, b). Thus, the opening over the planum has a trapezoidal shape, with the short bases at the level of the tuberculum sellae. During the bone opening, it is not so rare to cause bleeding of the superior intercavernous sinus. In such cases its management can be problematic and cause the operation to be longer, increase the blood loss and make more difficult the access to the intradural compartment. Apart the use of hemostatic agents, like Floseal® (Baxter, BioSciences, Vienna, Austria), it is preferable to close the sinus with the bipolar forceps instead of using the hemoclips, which narrows the dural opening. Two horizontal incisions are made just few millimetres above and below the superior intercavernous sinus. The sinus is then closed between the two tips of the bipolar forceps and coagulated in its median portion. It is incised with microscissors, and the two resulting dural flaps are coagulated to achieve their retraction and enlargement of the dural opening.

The dissection and the removal of the lesion in the suprasellar area follows the same principles of microsurgery and uses low-profile instruments and dedicated bipolar forceps. Also the strategy for tumor removal is tailored to each lesion, so that it will be different for giant pituitary adenomas, craniopharyngiomas or meningiomas.

- *Pituitary adenomas*

The transtuberculum transplanum approach for the removal of pituitary adenomas is required only for highly selected cases. In fact usually even for

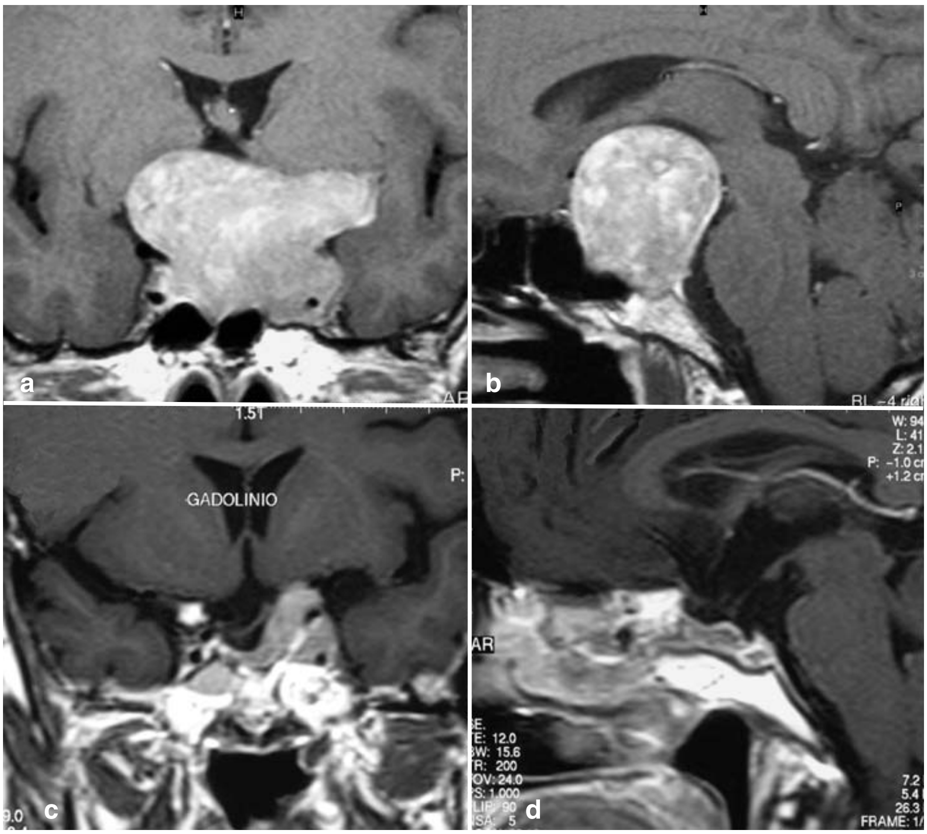

Fig. 15. a, b) Coronal and sagittal pre-operative MRI images showing a case of a giant adenoma. c, d) Coronal and sagittal post-operative MRI images of the same patient showing the subtotal removal of the lesion

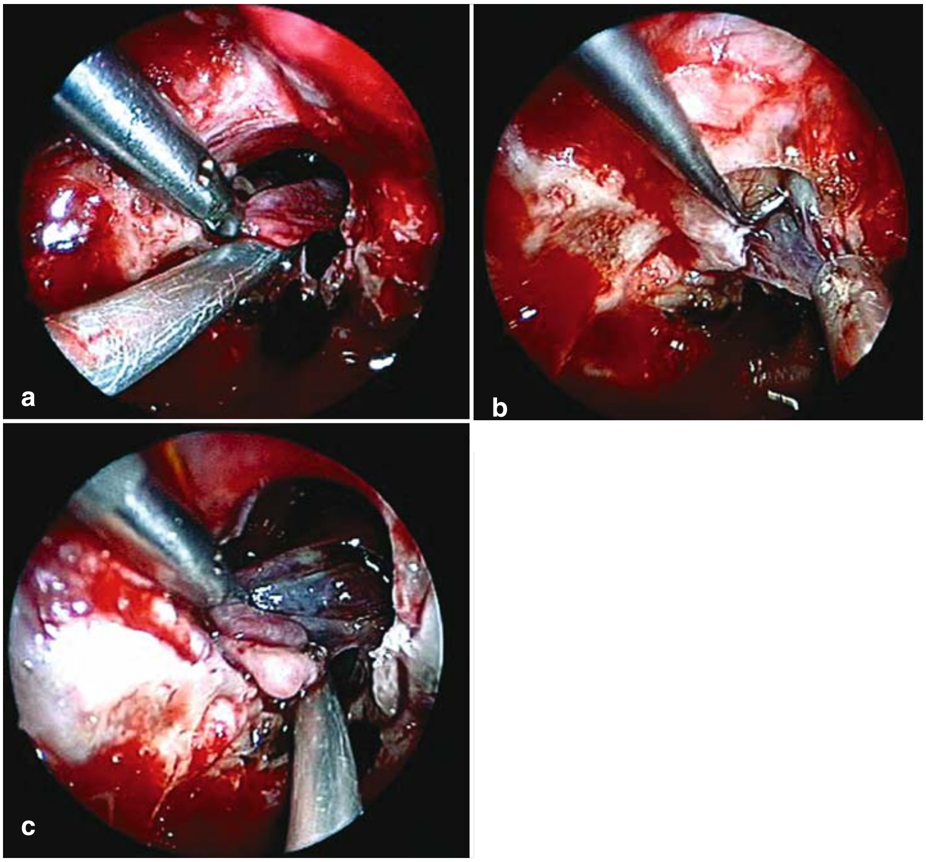

Fig. 16. Intraoperative pictures of the giant macroadenoma showed in Fig. 15. After the internal debulking (a), the tumor capsule (b, c) is dissected from the surrounding neurovascular structures and removed

very large intra-suprasellar pituitary adenomas, the trans-sellar approach allows the progressive descent of the suprasellar portion of the tumor and thence visualization of the suprasellar cistern.

In contrast, there are some conditions in which the extended approach can be used instead of the transcranial one, namely some purely suprasellar, or dumb-bell-shaped, and the giant pituitary adenomas (see Figs. 15 and 16).

- *Craniopharyngiomas*

Using the extended transplanar route in the cases of suprasellar craniopharyngiomas, the tumor is seen immediately after the dural opening, anterior to the chiasm and in front of the stalk. In contrast, in the case of intraventricular craniopharyngiomas, the tumor is not readily visible, because it is located behind the stalk and the chiasm and has to be approached passing laterally to the stalk. Working alternatively from both sides of the stalk, the dome of the tumor is

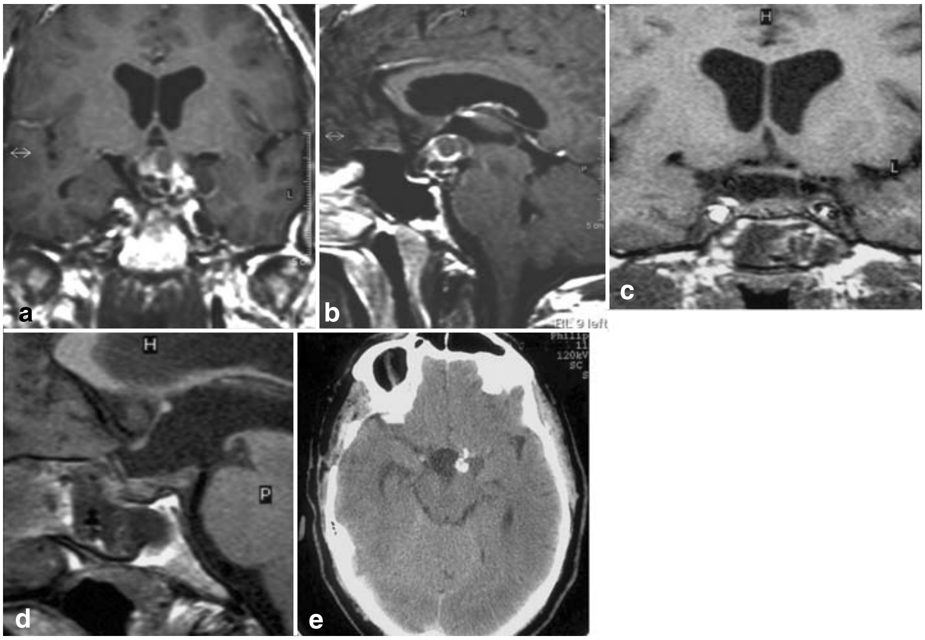

Fig. 17. a, b) Coronal and sagittal pre-operative MRI images showing a case of suprasellar craniopharyngioma already operated through a right pterional approach. c, d) Coronal and sagittal post-operative MRI images of the same patient showing the subtotal removal of the lesion. e) Early post-operative CT scan. Note the calcified remnant of the tumor

reached and manipulated. In this case the floor of the third ventricle is not early recognizable, because the lesion pushes it downward and behind, making it visible only after tumor removal and therefore care should be taken in preserving its integrity, specially at the level of the mammillary bodies. In cases of infundibular craniopharyngioma that had produced the swelling of the stalk, this was split allowing the removal of the craniopharyngioma. Tumor removal is performed according to the same paradigms of microsurgery: internal debulking of the solid part and/or cystic evacuation, avoiding the seeding of the craniopharyngioma tissue, followed by fine and meticulous dissection from the chiasm, the stalk and the superior hypophyseal arteries, while the AComA complex, located above the chiasm, andprotected by an arachnoidal sheath, is usually not involved in the procedure. The dissection is carried out under close-up view, with continuous and direct visual control of the neighbouring neurovascular structures.

At the end of the tumor resection, an inspection of the surgical cavity is made with 0 and 30 degrees endoscopes, in order to check the completeness of removal and to establish haemostasis (see Figs. 17 and 18).

Obviously this kind of approach presents some limits and contraindications for craniopharyngioma surgery. In cases of pre-sellar or conchal type of sinus,

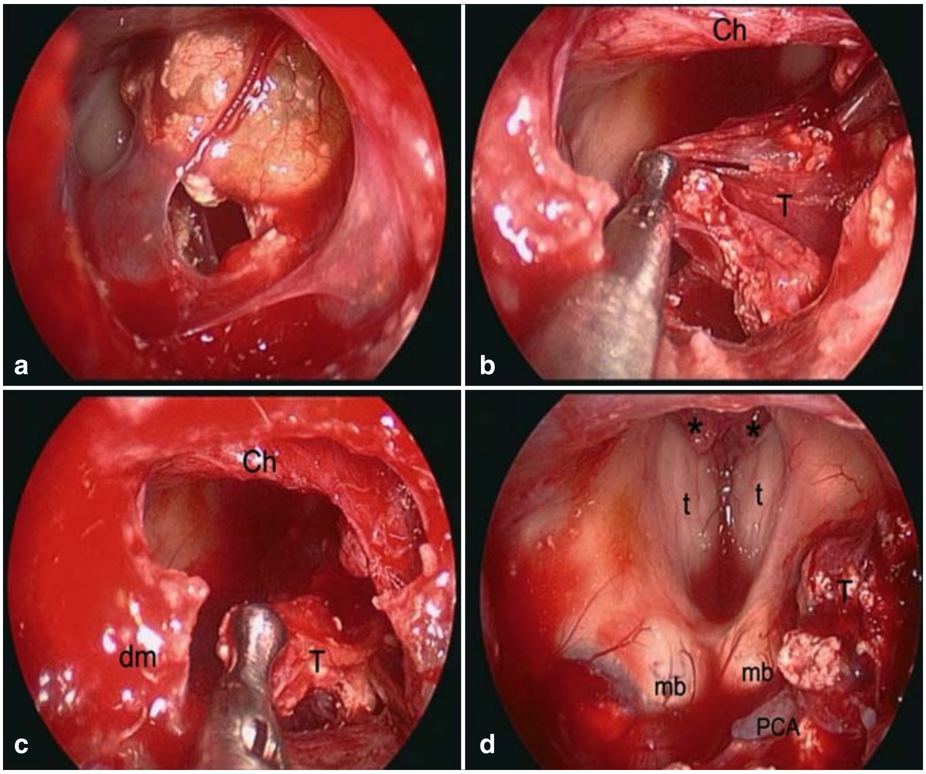

Fig. 18. Intraoperative pictures of the suprasellar craniopharyngioma showed in Fig. 17. a) initial visualization of the lesion after the dural opening. b, c) Piecemeal removal of the lesion. d) Endoscopic control after the removal. Note the presence of a calcified tumor remnant adherent to the left posterior communicating artery. *Ch* Chiasm; *T* tumor; *dm* dura mater; *t* thalamus; *mb* mammilary bodies; *PCA* posterior cerebral artery; * choroids plexus

the main landmarks within the sphenoid sinus are not easily recognizable, thus increasing the risk of injury to the intracavernous ICAs and the optic nerves. In cases of retrosellar extension of the lesion, the presence of a high dorsum can increase the difficulty of reaching and managing the tumor. The consistency, blood supply, and adherence to the surrounding neurovascular structures by the tumor can represent an obstacle to the approach. The narrow space for the instruments might create troubles in cases of hemorrhage. Other limitations are the steep learning curve before becoming confident with this peculiar view of the anatomical structures and the longer operative times at least initially when using a transcranial approach.

- *Tuberculum sellae meningiomas*

In the management of tuberculum sellae meningiomas (see Fig. 19a, b), tumor removal is preceded by the coagulation of the dural attachment,

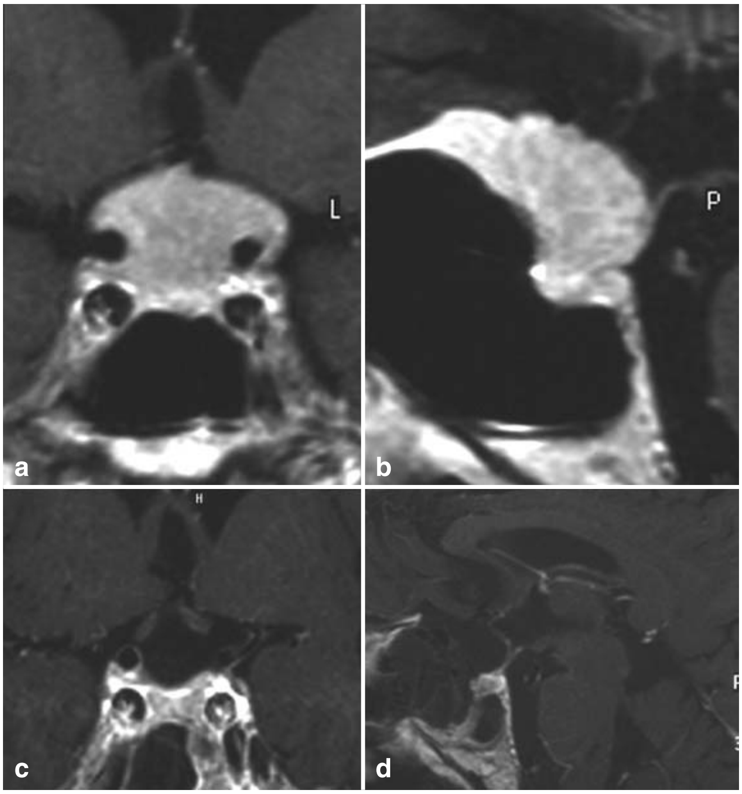

Fig. 19. a, b) Coronal and sagittal pre-operative MRI images showing a case of tuberculum sellae meningioma. c, d) Coronal and sagittal post-operative MRI images of the same patient confirming the total removal of the lesion

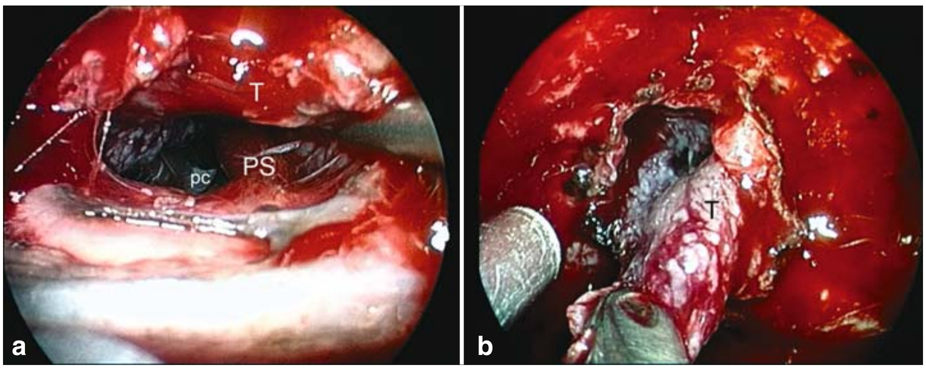

Fig. 20. Intraoperative pictures of the case of tuberculum sellae meningioma showed in Fig. 19. a) The mobilization of the inferior pole of the tumor permits to identify the pituitary stalk and the posterior clinoid process. b) Progressive internal debulking of the tumor mass. *T* Tumor; *Ps* pituitary stalk; *pc* posterior clinoid process

which permits an early tumor devascularization and offers an initial advantage. Then the dura and the underlying base of the meningioma is opened and the tumor is debulked with suction and radiofrequency cold bipolar coagulation (SurgiMax, Ellman Innovations, Oceanside, NY, U.S.A.). After the tumor is devascularized and debulked, the surrounding arachnoid is dissected away from the tumor's capsule. Usually the dissection starts from the inferior pole of the tumor which is elevated allowing the early identification of the pituitary stalk, of the optic nerves' inferior aspect and of the chiasm and both the superior hypophyseal arteries (see Fig. 20a, b). Gently blunt dissection of the tumor from the inferior surface of the optic nerves and chiasm is performed, with a meticulous identification and preservation of the vascular supply to the under face of the optic pathway. After the inferior aspect of the optic apparatus has been freed from the tumor, the

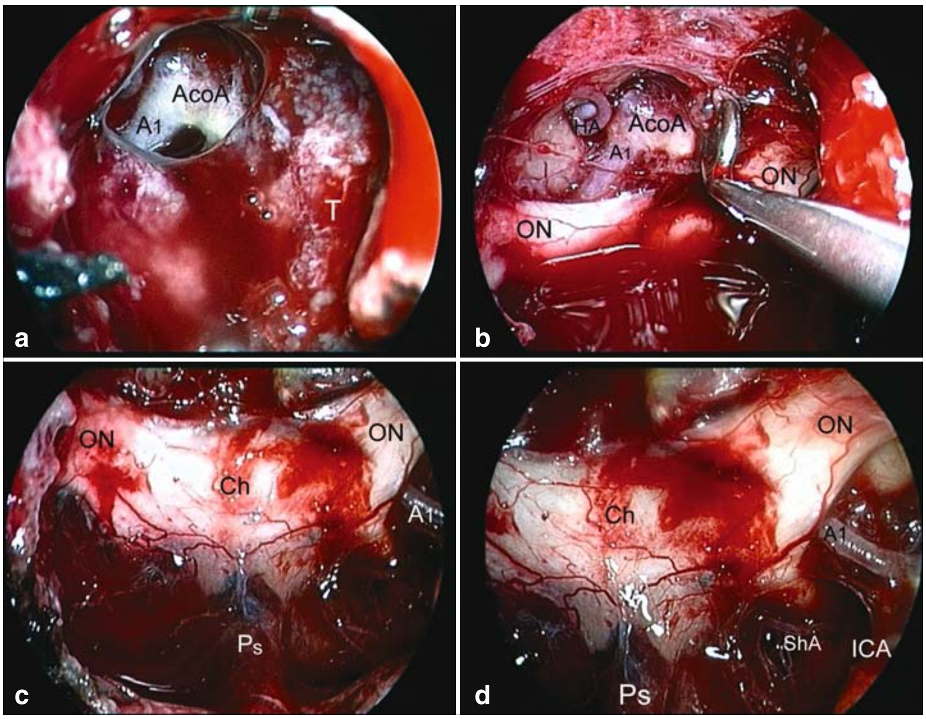

Fig. 21. Intraoperative pictures of the case of tuberculum sellae meningioma showed in Fig. 19. a, b) The superior aspect of the tumor was dissected from the anterior part of the Willis' circle. c, d) After the lesion removal, the panoramic endoscopic view of the surgical cavity shows the chiasm, the optic nerves and the A1 segment of the left anterior cerebral artery. *Ch* Chiasm; *ON* optic nerve; *A1* anterior cerebral artery; *A2* anterior cerebral artery; *AcoA* anterior communicating artery; *Ps* pituitary stalk; *ICA* internal carotid artery

lateral and the superior part of the tumor are dissected. Proceeding towards the lateral part of the meningioma, an arachnoidal plane is usually found against the internal carotid arteries. The safe removal of the upper pole of the tumor requires gentle pulling of the capsule from below, which brings into direct view the suprachiasmatic area, where there is the AComA complex. The arachnoidal layers are dissected and these arteries are freed (see Fig. 21a, b). Once the tumor has been freed from any adherence, it is removed. In the final step of the procedure the operative field is inspected and accurate hemostasis is checked (see Fig. 21c, d).

As for craniopharyngiomas, the transtuberculum/transplanum approach to tuberculum sellae meningiomas presents some disadvantages related to the approach and to the characteristic of the tumor itself. The degree of pneumatization of the sphenoid sinus is important for the recognization of the main landmarks within the sphenoid sinus and to guarantee safe bone removal; in the case of a small sella, the distance between the optic nerves and the ICAs is narrower and potentially more dangerous. Concerning the tumor-related limits, we consider as contraindication for the extended transsphenoidal approach either the involvement of the optic canal and the encasement of the 3rd cranial nerve. Finally a more anterior dural attachment requires a very large osteo-dural opening, thus increasing the difficulties of the skull base reconstruction.

Approach to the ethmoidal planum

The introduction of functional endoscopic sinus surgery (FESS) in the early eighties allowed the ENT surgeons to approach chronic inflammatory pathologies of the nasal and paranasal sinuses [94, 112, 141–144]. Their experience has improved knowledge of the anatomy of this area and resulted in the evolution of the endoscopic approach to the anterior skull base. Due to its lesser surgical morbidity as compared to other techniques, the endoscopic endonasal technique for the management of lesions of spheno-ethmoidal region has become popular for CSF leaks, and subsequently for meningoencephaloceles (see Figs. 22, 23 and 24) and selected benign tumors of the anterior skull base [20, 70, 74, 108, 123, 147]. More recently the collaboration among ENT surgeons and neurosurgeons has brought advances in the use of the endoscopic endonasal technique in neurosurgery, thus permitting the pure endonasal treatment of intradural lesions, such as olfactory groove meningiomas or esthesioneuroblastomas [86]. The surgical approach to the ethmoid planum is tailored to the position and to the extension of the lesion. In this way it will be different for CSF leaks, meningoencephaloceles and tumors located on the cribiform plate. While approaching this region it is important to exactly know the position of some relevant structures, such as the anterior

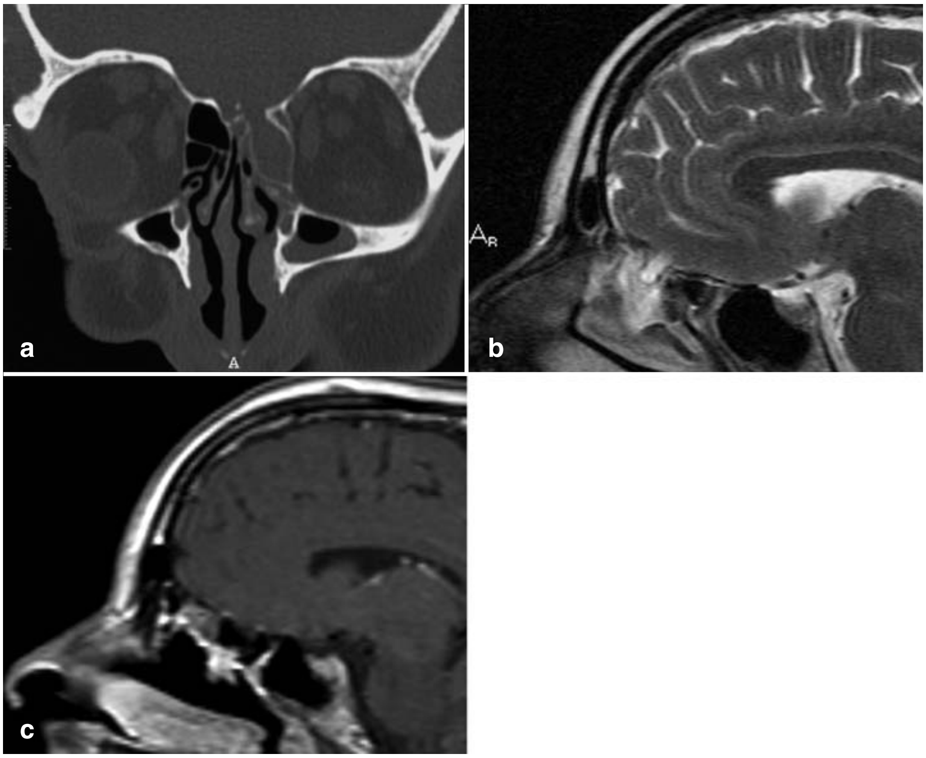

Fig. 22. Pre-operative neuroradiological studies showing a left ethmoidal meningoencephalocele. a) Coronal CT scan and b) sagittal MRI. c) Post-operative sagittal MRI, showing the complete removal of the meningoencephalocele and presence of reconstruction material in the anterior ethmoid

and posterior ethmoidal arteries or the papyracea, to avoid complications especially to the orbit.

Approaches to the cavernous sinus and lateral recess of the sphenoid sinus (LRSS)

Different types of transcranial approaches have been adopted and popularized for the treatment of the cavernous sinus pathologies [44, 119, 135]. However these approaches require neuro-vascular manipulation and are related to a significant rate of morbidity and mortality. In order to reduce the risk of cranial nerves damage, a variety of transsphenoidal, transmaxillary, transmaxillosphenoidal, transethmoidal and transsphenoethmoidal microsurgical approaches have been proposed over the past two decades to remove lesions involving the anterior portion of the cavernous sinus [32, 37, 50, 54, 71, 75, 96, 99, 126]. These extradural approaches offer direct access to the anterior portion of the

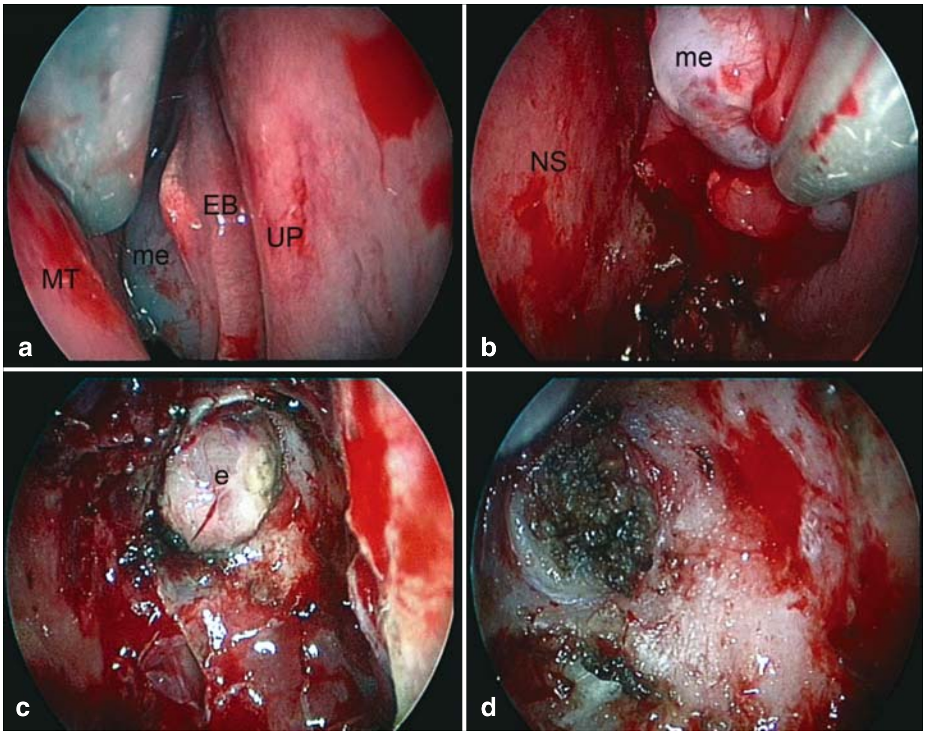

Fig. 23. Endoscopic endonasal removal of the meningoencephalocele showed in Fig. 22. a) Passing laterally to the middle turbinate, the meningoencephalocele becomes immediately visible. b) After removal of the middle turbinate, the sac of the meningoencephalocele is better identificated. c) After the removal of the meningeal layer, the encephalocele is identificated. d) The encephalocele is coagulated. *e* Encephalocele; *NS* nasal septum; *MT* middle turbinate; *EB* ethmoid bulla; *UP* uncinate process; *me* meningoencephalocele

cavernous sinus, but are limited by a deep, narrow surgical corridor that does not allow either an adequate exposure of the surgical field, specially of the lateral compartment of the cavernous sinus. The increasing use of the endoscope in transsphenoidal pituitary surgery has led some authors to consider the feasibility of the endoscopic transsphenoidal approach in the treatment of selected lesions arising from or involving this area, such as pituitary adenomas and chordomas [55, 83].

Different endoscopic endonasal surgical corridors have been described to gain access to different areas of the cavernous sinus [2, 55]. These corridors have been related to the position of the intracavernous carotid artery (ICA). The first approach permits access to a compartment of the cavernous sinus medial to the ICA, while a second approach allows access to a compartment lateral to the ICA.

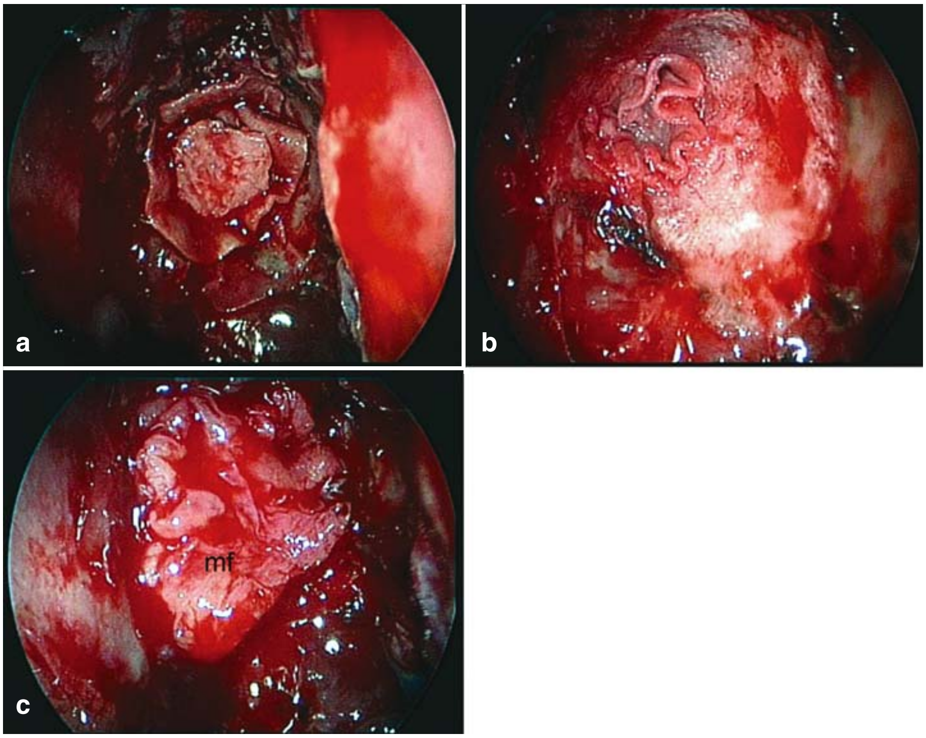

Fig. 24. Endoscopic endonasal removal of the meningoencephalocele showed in Fig. 22. Reconstruction of the bone and dural defects a, b) a single layer of dural substitute (bovine pericardium) and a sized piece of LactoSorb® have been positioned extradurally on the bone-dural defect and pushed intradurally. c) The reconstruction is completed with the positioning of the muchoperichondrium harvested from the middle turbinate. *mf* Mucosal flap

- *Approach to the medial compartment of the cavernous sinus*

The approach to the medial compartment is indicated for lesions arising from the sella and projecting through the medial wall of the cavernous sinus, without extension into the lateral compartment. Actually it is mainly indicated in cases of pituitary adenomas. The procedure begins with the introduction of the endoscope through the nostril controlateral to the parasellar extension of the lesion. This because the endoscopic approach is paramedian and the view provided by the endoscope is much wider on the contralateral side. After the sphenoidotomy and the accurate identification of all the bony landmarks on the sphenoid sinus posterior wall, the sellar floor and the dura are widely opened on the same side of the parasellar extension of the lesion. After the removal of the intra-suprasellar portion of pituitary adenoma, the intracavernous portion of the lesion is faced. The tumor itself enlarges the C-shaped parasellar carotid artery, thus making easier the suctioning and the curettage through this corridor. The completeness of the lesion removal is confirmed by the venous bleeding, easily controlled with irrigation and temporary sellar packing with haemostatic agents and/or cottonoids.

- *Approach to the lateral compartment of the cavernous sinus and to the lateral recess of the sphenoid sinus (LRSS)*

The approach to the lateral compartment is indicated in the case of tumors involving the entire cavernous sinus and arising from the sella, such as pituitary adenomas, or lesions coming from surrounding areas (middle cranial fossa, clivus, pterygopalatine fossa), such as chordomas and chondrosarcomas. This approach is ipsilateral to the parasellar extension of the lesion. In the nasal phase of the approach, the surgical corridor is created by the removal of the middle turbinate, the lateralization of the middle turbinate in the other nostril and the removal of the posterior part of the nasal septum. The anterior wall of the sphenoid sinus and its septa are then widely removed in order to expose all the landmarks on the posterior wall of the sphenoid sinus. The bulla ethmoidalis and the anterior and posterior ethmoid cells are removed on the same side of the parasellar extension of the lesion, to create a wide surgical corridor between the nasal septum and the lamina papiracea. In order to preserve the medial wall of the orbit and the anterior and posterior ethmoidal arteries, an extensive lateral and superior surgical exposure has to be avoided while anterior and posterior ethmoid cells are opened.

The nasal mucosa covering the vertical process of the palatine bone is dissected around the tail of the middle turbinate and carried upwards to identify the spheno-palatine foramen. The orbital process of the palatine bone and part of the posterior wall of the maxillary sinus are removed. The spheno-palatine artery is then isolated with bipolar coagulation or the use of haemoclip, if necessary At this point the medial pterygoid process is removed, with the microdrill providing a direct access to the lateral recess of the sphenoid sinus (LRSS) and thus to the lateral compartment of the cavernous sinus.

Once the anterior face of the lesion has been exposed, before opening the dura, the use of Neuronavigation and the micro-Doppler is mandatory in identifying the exact position of the ICA. The tumor removal proceeds from the extracavernous to the intracavernous portion. In the case of tumours occupying mainly the lateral compartment of the cavernous sinus, the growth of the lesion usually displaces the ICA medially and pushies the cranial nerves laterally. The dura is then opened as far as possible from the ICA, which, in case of pituitary adenomas, allows the lesion to emerge under pressure. Delicate manouveres of curettage and suction usually allow the removal of the parasellar portion of the lesion, in the same fashion as for the intrasellar portion. Only after the removal has been completed will some bleeding begin, which is usually easily controlled with the use of hemostatic agents.

Approach to the clivus, cranio-vertebral junction and anterior portion of the foramen magnum

The retroclival area and the cranio-vertebral junction can be involved in numerous and different disorders: intradural and extradural tumors, bone malformations, inflammatory diseases and trauma. Several approaches to these regions have been developed through anterior, antero-lateral and postero-lateral routes [6, 34, 36, 67, 93, 104, 111, 118, 128]. The most physiological and shortest route to the clival area and the anterior aspect of the cranio-vertebral junction is represented by an anterior approach through the pharynx. The transoral approach has been mainly used for treatment of extradural lesions and craniovertebral junction decompression and some authors have reported the treatment of intradural lesions [35, 72, 116]. The endoscope through the nose has been used for the management of clival lesions and more recently also for lesions located at the CVJ, either extradural [59, 84, 87, 89, 90] or intradural

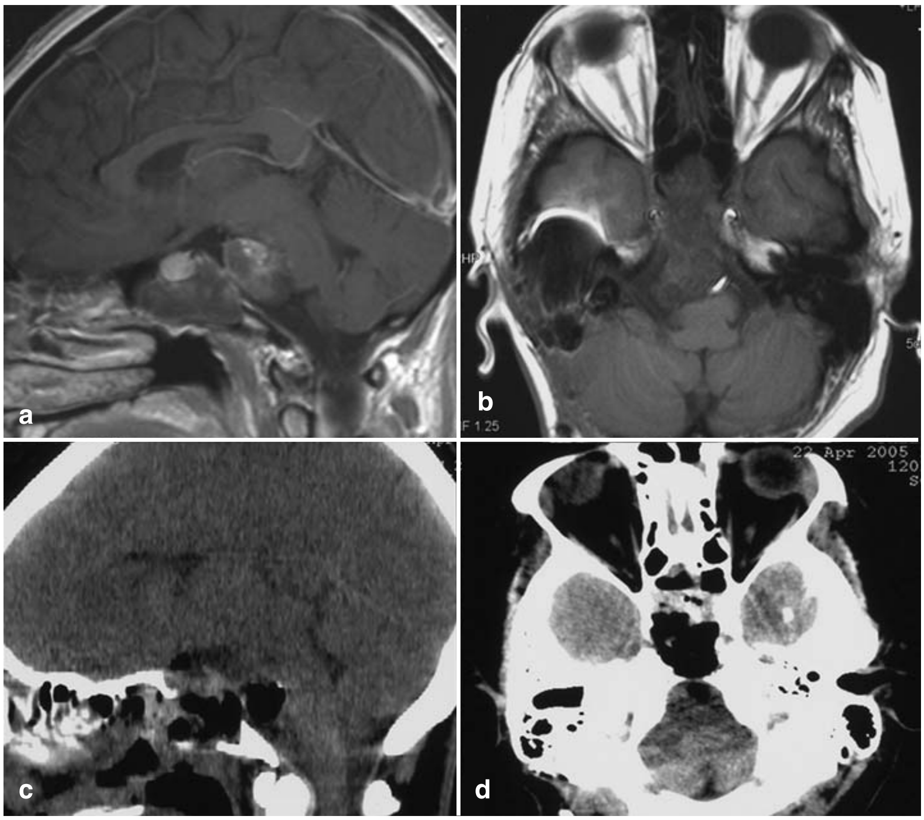

Fig. 25. a, b) Sagittal and coronal pre-operative MRI images showing a case of clival chordoma. c, d) Sagittal and coronal post-operative CT images of the same patient showing the subtotal removal of the lesion

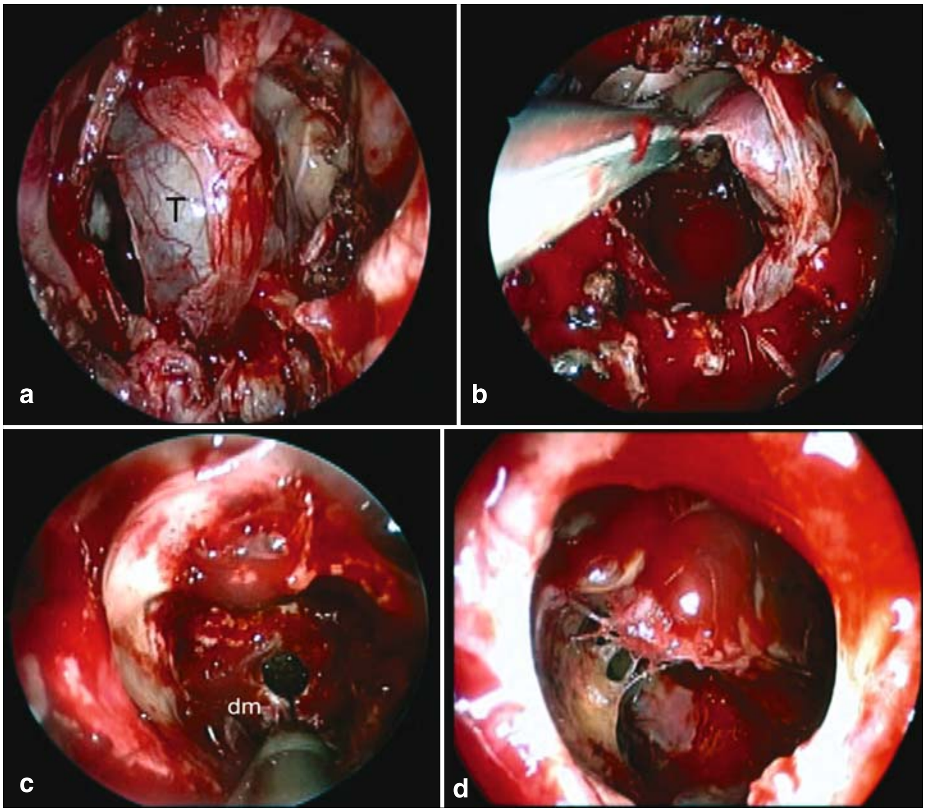

Fig. 26. Intraoperative pictures of the case of clival cordoma showed in Fig. 25. a) After performing the anterior sphenoidotomy, the tumor becomes immediately visible. b) The tumor has completely eroded the clival bone and is removed in piecemeal fashion after central debulking. c) After removal of the extradural portion of the tumor, a dural defect was identificated. d) Close up view through the dural defect during the intradural removal of the tumor mass

[89, 139] (see Figs. 25 and 26). The endoscopic endonasal approach provides the same advantages of direct route and minimal neurovascular manipulation offered by the transoral approach, but with a wider and closer view. Furthermore it avoids some of the disadvantages related to the transoral approach, such as the need for mouth retractors and splitting of the soft palate. However these approaches actually share some limits, that are the inadequate exposure of the lateral aspects of large tumors and the risk of meningitis and cerebrospinal fluid (CSF) leak, specially in case of intradural extension of the lesion.

- *Surgical procedure*

The access to the clivus needs a lower trajectory in respect to that necessary for the sellar region. After the preliminary steps (middle turbinectomy, removal of the posterior par of the nasal septum, wide sphenoidotomy) the procedure goes on with the removal of the inferior wall of the sphenoid sinus up to identify the Vidian nerves, that represent the lateral limits of the surgical corridor. The vomer and the inferior wall of the sphenoid sinus are completely removed, preserving the mucosa covering these structures, in order to create an useful mucosal flap for the closure of the surgical field. The bone of the clivus, according with the surgical necessity, is drilled and removed. At the level of the sphenoidal portion of the clivus the approach is limited laterally by the bony protuberances of intracavernous carotid artery. Furthermore it is important to highlight that the abducens nerve enters the cavernous sinus by passing through the basilar sinus medially than the paraclival tract of the intracavernous carotid artery; therefore particular attention should be paid during bone removal in this area in order to avoid damage to this nerve. In case of lower extension of the lesion, it is possible to extend downward the bone removal up to the C2 vertebral body.

Reconstruction techniques

Reconstruction of the sella is a fundamental step of the procedure, either in microsurgical and endoscopic transsphenoidal surgery [13, 21, 137]. During an extended endoscopic endonasal approach, especially to the suprasellar area or to the clivus, a large osteo-dural opening is usually necessary and the subarachnoid space is often deliberatively entered. As a matter of facts, the creation of an intraoperative CSF leakage could be considered part of the surgical technique in extended transsphenoidal approach. Thus, the presence of a conspicuous intraoperative CSF leakage requires effective closures techniques to successfully avoid postoperative CSF leaks and the related undesirable complications (namely, meningitis and hypertensive pneumocephalus). Such complications are directly related with the failure of the skull base reconstruction at the end of the operation and the consequent postoperative CSF leak, which has been reported to as high as 65% of cases; however, it ranges from 9 to 21% [45, 49, 60, 61, 85, 91, 138]. Bacterial meningitis has been reported ranging from 0.5 to 14% [10, 30, 49, 51, 85] while tension pneoumocephalus occurs in fewer than 0.5% of cases and can be precipitated by lumbar CSF diversion in presence of an inadequate cranial base reconstruction [7, 49, 131, 132].

The presence of large osteo-dural defects makes inadequate the use of the conventional sellar floor reconstruction techniques, even though the criteria remain the same. During these extended approaches, the brain pulsation exerts high pressures over the wide skull base defect. For this reason a hard but easy to shape material is needed to create an initial barrier against the cranial pressure. In the majority of cases a synthetic copolymer of 82% polylactic acid and 18% polyglycolic acid (LactoSorb, Walter Lorenz Surgical, Inc., Jacksonville, FL) has been used. It becomes malleable at a temperature of 70°, making it easy to be shaped according to the defects, and becomes rigid in few seconds of cooling at room temperature. It is completely reabsorbed within 1 year, decreasing the risk of foreign body reaction. As a dural substitute, that has to be combined with the bone substitute, the human pericardium is used (Tutoplast®). This material is very malleable, easy to cut with scissors and also simple to distend over the skull base defect.

In our experience [26], we have adopted three different reconstruction techniques, according with the different surgical conditions.

1. Intradural reconstruction (so-called inlay). This type of reconstruction is easily performed when the size of the bony and dural openings coincide. A large fragment of dehydrated human pericardium is positioned to cover the entire dural and bony defect. Then, a piece of Lactosorb®, that has been previously cut slightly larger than the dural opening, is gently pushed against the dural substitute through the dural edges. In this way the dural substitute is transposed intradurally, as well as the fragment of Lactosorb®, remaining extradural the exceeding borders of the pericardium (see Fig. 27).
2. Intra-extradural reconstruction (inlay-overlay). This technique can be realized only when the dural window is smaller than the bony defect. A fragment of pericardium is fashioned and cut to a size a little bit larger than that of the dural window. The soft consistence of this material permits its easy insertion in an underlay position. A piece of Lactosorb® is then embedded extradurally, in a manner such that it is supported by at least two opposed edges of the bony defect, thus totally covering the dural defect beneath (see Fig. 28).

Fig. 27. Schematic drawings showing the so-called intradural (inlay) technique

Fig. 28. Schematic drawings showing the intra-extradural (inlay-overlay) technique

3. Extradural reconstruction (overlay). A large piece of human pericardium is placed over the bony defect, but the fragment of Lactosorb® is embedded in the extradural space dragging the dural substitute in overlay position. This kind of reconstruction seems to provide the most effective watertight barrier against CSF (see Fig. 29).

Fig. 29. Schematic drawings showing the extradural (overlay) technique

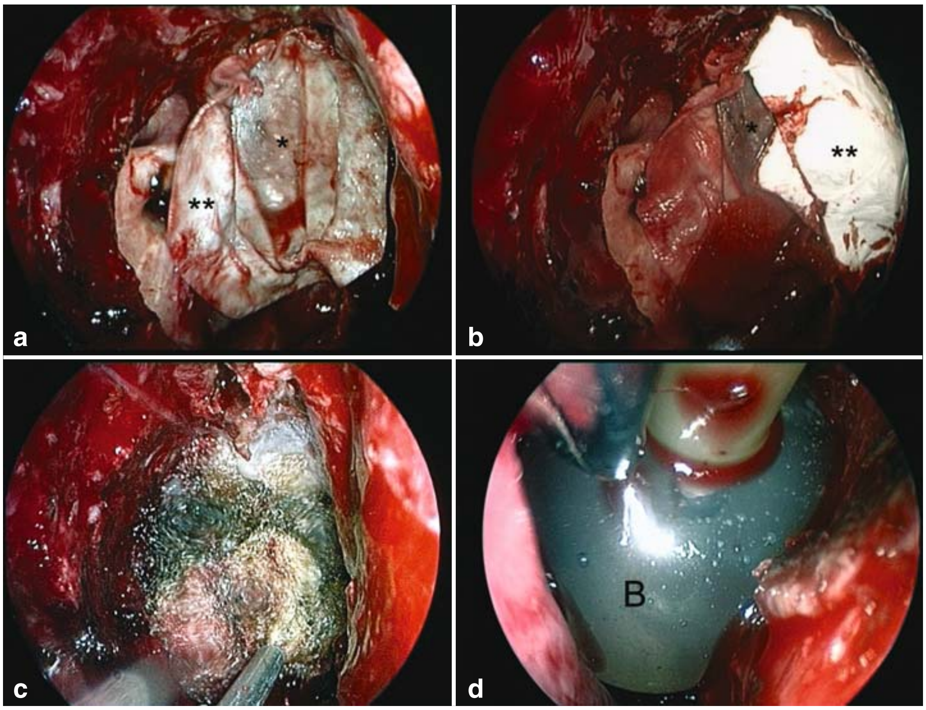

Fig. 30. Intraoperative image of the extradural (overlay) technique. a) The fragments of Tutoplast® and Lactosorb® are in the extradural space and the exceeding borders of the dural substitute cover the surrounding bone. b) A multilayer apposition of dural substitute was performed. c) Packing of the sphenoid sinus was performed with surgicel and fibrin glue. d) A 12-French Foley catheter inflated with 8 cc of saline solution was positioned in front of the sphenoid sinus to hold the reconstruction materials. * Lactosorb®; ** Tutoplast®; *B* balloon

After the osteo-dural defect has been sealed, the reconstruction continues with the packing of the sphenoid sinus.

Fragments of dural substitute are placed in multilayer fashion on the posterior wall of the sphenoid sinus, covering the skull base defect and the surrounding bone, where the mucosa has been stripped to favor adherence. The remaining sphenoid cavity is filled with surgicel and fibrin glue. The vascularized mucoperichondral septal flap, prepared at the beginning of the operation, as previously described, is then used to cover the skull base defect and the entire posterior wall of the sphenoid sinus [66]. An inflated Foley catheter (12–14 French), filled with 7–8 cc of physiologic solution, is placed in front of the sphenoid sinus cavity, to support the reconstruction (see Fig. 30). The Foley catheter is usually removed five days after the operation. After its removal an endoscopic inspection of the nasal cavities is performed, to check the correct positioning of the reconstruction materials and the eventual presence of CSF leak. Postoperative lumbar CSF drainage is not usually used.

Results and complications

Between January 2004 and April 2006 we performed 33 extended endonasal transsphenoidal approaches for lesions arising from or involving the sellar region and the surrounding areas. The most representative pathologies of this series were the ten craniopharyngiomas, the six giant adenomas and the five meningiomas; we also used this procedure in three cases of chordomas, three of Rathke's cleft cysts and three of meningo-encephaloceles, one case of optic nerve glioma, one olfactory groove neuroendocrine tumor and one case of fibro-osseous dysplasia. Twenty patients were females and thirteen were males (mean age 47, 3 years) (see Table 1).

Table 1. *Patient series*

Disease	No. of cases
Tuberculum sellae meningiomas	4
Clival meningioma	1
Craniopahryngiomas	10
Rathke's cleft cysts	3
Giant pituitary adenomas	6
Meningo-encephaloceles	3
Clival chordomas	3
Optic nerve glioma	1
Olphactory groove neuroendocrine tumor	1
Fibro-osseous displasia	1
Total	33

Table 2. *Craniopharyngiomas' series*

Age/ sex	Tumor location	Tumor charac-teristics	Pre-operative signs	Pre-operative visual symptoms	Previous surgical procedures	Tumor removal	Complications	Postoperative endocrinol outcome	Post-operative visual outcome
70, F	Infrasellar Suprasellar	Cystic	–	BT hemianopia	Transcranial approach	Total	–	–	Improved
58, M	Infrasellar Suprasellar	Solid	Pan HP DI	BT hemianopia AD (R 1/200; L 1/20)	Trans-sphenoidal approach	Subtotal	CSF leak	Unchanged	Improved
68, M	Intra-extraventricular	Solid	–	SBT quadrantopia	–	Total	–	Pan-HP	Improved
63, M	Suprasellar	Cystic + Solid	–	BT hemianopia AD (R 1/30)	Transcranial approach	Subtotal	–	–	Improved
58, M	Intra-extraventricular	Cystic + Solid	Pan HP DI	–	Transcranial approach	Total	–	Unchanged	–
57, M	Intraventricular	Solid	Pan HP	BT hemianopia AD (L 1/30)	–	Total	CSF leak DI	Unchanged	Improved
47, F	Intra-extraventricular	Cystic + Solid	DI	AD (R 1/30; L 2/10)	–	Partial	–	Unchanged	Improved R Worsening L
57, F	Intra-extraventricular + Hydrocephalus	Cystic + Solid	Progressive neurological deterioration	–	–	Total	Brainstem hemorrhage	–	–
68, M	Intra-extraventricular	Cystic + Solid	Pan HP	BT hemianopia AD (R 6/10; L 3/10)	–	–	DI CSDH	Unchanged	Improved
26, F	Intra-extraventricular	Cystic + Solid	Hyperprolact	–	–	Total	DI	Unchanged	–

N Normal size; *Pan HP* panhypopituitarism; *DI* diabetes insipidus; *BT* bitemporal; *SBT* superior bitemporal; *VA* visual acuity; *CSDH* chronic subdural hematoma.

Tumor removal, as assessed by post-operative MRI, revealed complete removal of the lesion in 2/6 pituitary adenomas, 7/10 craniopharyngiomas (see Table 2), 4/5 meningiomas, 3/3 Rathke's cleft cyst, 3/3 meningo-encephalocele. Subtotal removal (>80% based on the three-month post-operative 1.5 Tesla sellar MRI) was obtained in the four giant pituitary adenomas (3 non-functioning and 1 PRL-secreting) because of the extensive involvement of one or both the cavernous sinuses, in 3 craniopharyngiomas, in one clival meningioma, in one chordoma, and either in the case of optic nerve glioma and olphactory groove neuroendocrine tumor. Finally only partial removal was possible for one craniopharyngioma and two chordomas and biopsy only was performed in the case of fibro-osseous dysplasia.

In two cases of craniopharyngiomas, the incomplete removal was due to the partial calcification of the lesion, firmly adherent to the left posterior cerebral artery in the first one, and of a portion of capsule to the right optic nerve in the other. One patient underwent a partial removal because the pituitary stalk and the infundibular recess of the third ventricle were diffusely involved by the lesion and some remnants were intentionally left to avoid making pituitary function worse in the young patient.

Of 13 subjects with pre-operative visual function defects, three patients with meningioma had a complete recovery and six, who had a craniopharyngioma, improved; in one patient with a giant non-functioning pituitary macroadenoma, a preoperative severe bitemporal haemianopia occurred postoperatively further worsening vision in the left eye, with the only persistence of the light perception. We observed worsening of visual acuity in one eye and improvement in the other in three cases; the first one was a patient with craniopharyngioma, the second was the patient with the optic nerve glioma and the third was a patient with an infra-extraventricular craniopharyngioma.

Concerning surgical complications, 3 patients, two with a craniopharyngioma, one with a clival meningioma and one with a recurrent giant pituitary macroadenoma involving the entire left cavernous sinus, developed a CSF leak and a second operation was necessary in order to review the cranial base reconstruction and seal the leak. One of them (the patient with the giant Knosp grade 4 pituitary adenoma) developed a bacterial meningitis, which resolved after a cycle of intravenous antibiotic therapy with no permanent neurological deficits. One patient with an intra-suprasellar non-functioning adenoma presented with a generalized epileptic seizure a few hours after the surgical procedure, due to the intraoperative massive CSF loss and consequent presence of intracranial air. In one case of craniopharyngioma immediately after the procedure we observed rapid worsening of the level of consciousness and bilateral midriasis. CT scan showed a brain stem haemorrhage. The patient died few days later.

Pituitary dysfunction did not improve in any patient who already had some degree of pituitary hypofunction; however only one postoperative additional hypopituitarism was reported. In three cases of craniopharyngioma and in one case of meningioma a new permanent diabetes insipidus was observed. One patient developed a sphenoid sinus mycosis, cured with antimycotic therapy. Epistaxis and airway difficulties were never observed.

Conclusions

The endoscope, after Gerard Guiot's first attempt to explore the sellar cavity following the lesion removal [65] and, then, after the endonasal experience of the ENT surgeons in Functional Endoscopic Sinus Surgery (FESS) [94, 141, 142, 145], has gained a stable position in transsphenoidal surgery, due to its vision inside the anatomy that offers wider view of the target area and permits to perform less invasive approaches.

The experience in surgery of the sellar region, the wide area of vision of the endoscope and the attainment of a specific endoscopic skill have gradually permitted to extend the area of the approach to the suprasellar, parasellar and infrasellar regions. The target of the surgical deed in transnasal surgery can be directed towards pathologies once approachable only with the more invasive transcranial surgery [8, 14, 15, 19, 39, 81]. Indeed, such extended endoscopic approaches, although at a first glance might be considered something that everyone can do, require an advanced and specialized training, either in the lab, with *ad hoc* anatomical dissections, and in the operating room, after having performed a sufficient number of standard sellar operations and having become familiar with the endoscopic skill, endoscopic anatomy and complication avoidance and management.

It is difficult today to define the boundaries and the future limits of the transsphenoidal extended approaches because the work is still in progress, but the train has moved and is bringing with it technical advances of which we think that patients and young generations will benefit.

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