REVIEW ARTICLE

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Extended endoscopic endonasal skull base surgery: from the sella to the anterior and posterior cranial fossa

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Abstract

Skull base surgery has gone through significant changes with the development of extended endoscopic endonasal approaches over the last decade. Initially used for the transphenoidal removal of hypophyseal adenomas, the endoscopic transnasal approach gradually evolved into a way of accessing the whole ventral skull base. Improved visualization, avoidance of brain retraction, the ability to access directly tumours with minimal damage to critical neurosurgical structures as well lack of external scars are among its obvious benefits. However, it presents the surgeons with a number of challenges, including the need to deal endoscopically with potential arterial bleeding, complicated reconstruction requirements as well as the need for a true team approach. In this review drawing from our experience as well as published series, we present an overview of current indications, challenges and limitations of the expanded endonasal approaches to the skull base.

Introduction

The skull base forms the floor of the cranial cavity and separates the brain from the facial skeleton. By virtue of its role as an interface, skull base is one of the most complex anatomical areas of the human body.

The variability of pathology present in skull base and the fact that it is not readily accessible have generated for many years a significant amount of interest and controversy. Early on, it was understood that using the endoscope could facilitate the access to the brain: Walter Dandy is considered the father of neuroendoscopy,[1] and reported already in 1932 similar outcomes between standard (via craniotomy) and endoscopic excision of choroid plexus for the treatment of hydrocephalus.[2] However, it was a resident urologist from Chicago, Victor Darwin Lespinasse (1878–1946), who described for the first time the use of a modified cystoscope (sic) for the performance of an intracranial intraventricular endoscopy to treat hydrocephalus.[3]

The introduction of the rigid endoscope by Nitze[4] and Hopkins who patented the rigid lens in 1960[5] transformed the way surgery is performed. Karl Storz further improved the endoscope by adding fibre optics[5] while a charge-coupled device camera was added by Bell laboratories.[6]

Otolaryngologists were the first to use the endoscope in and through the nasal cavity, But Gerard Guiot was the first neurosurgeon to use the endoscope in the trans-sphenoidal approach towards the skull base in 1963.[7] However, he had to abandon this procedure because of poor visualization, and following him, for many years, it felt that the endoscope was to be used in addition to the microscope as a visual aid rather than as the primary mean of visualization. The explosion of endoscopic sinus surgery following the groundbreaking work of Stammberger in the 1980s led eventually in 1992 for Jankowski and co-workers from the Central Hospital of the University of Nancy to report for the first time the removal of of hypophyseal tumours in three patients using a purely endoscopic transnasal transsphenoidal approach to the sella.[8]

A number of pioneers of transnasal endoscopic skull base surgery subsequently emerged, including Jho and Carrau, a neurosurgeon and otolaryngologist, respectively, from Pittsburgh.[1] Furthermore, Cappabianca and de Divitiis from Naples[2] and Frank and Pasquini from Bologna[3] pushed further the limits of what can be achieved via a transnasal endoscopic approach. More recently, the 'Pittsburgh team', consisting of neurosurgeon Amin Kassam and otorhinolaryngologists Ricardo L. Carrau and Carl Snydermann from the University of Pittsburgh Medical Centre, drawing from their experience of more than 1000 procedures, further systematized

endonasal endoscopic approaches and introduced the concept of sagittal and coronal modules describing the various transnasal corridors to the various compartments of skull base.[9–12] The last decade it became clear that the entire ventral skull base is accessible using an endonasal approach.[9] This has been termed the expanded endonasal approach (EEA)[12] and provides access to the anterior, middle and posterior cranial fossa.[13] However, it is a 'tumour – tailored' approach, with different tumours in different locations requiring different techniques. There have been a number of problems encountered by the early pioneers of this type of surgery, not least of which was the high rate of cerebrospinal fluid (CSF) leaks. All of this is changing with novel ways of reconstructing large dural defects and the arrival of true team surgery.

In this article we aim, using some of our cases as an example, to give some insight in the current status of expanded endoscopic endonasal approach including its indications as well as its limitations.

Developments in EEA

Why favour EEA over traditional approaches?

Pathway to the tumour

Choosing the most direct approach to the tumour is vital in skull base surgery. Avoidance of frontal lobe retraction with its associated temporary (and occasionally permanent) neurological deficits is obviously a reason to favour the transnasal approach (Table 1) to traditional transcranial approaches. However, even more importantly, from an oncological resection point of view, unimpaired visualization and access are important: Critical neurovascular structures (the carotid, the optic nerves, the oculomotor nerve, etc.) may block such direct access. For example, in a patient who has a retrochiasmatic craniophrayngioma which is growing postero inferior to the optic nerve as clearly identifiable on the preoperative magnetic resonance imaging (MRI) scans, an EEA provides the most direct pathway to the tumour without the optic nerve obstructing access, as would be the case in a transcranial approach. This has been articulated by the Pittsburgh group, as the concept of 'not crossing the nerves' – in other words, always chose the approach that does not include dissecting 'behind' a critical neurovascular structure.

'True team'[14] surgery

Traditionally, 'team' surgery was defined as surgeons working sequentially. However, both technically as well as conceptually, this approach is not valid in EEA: the anatomical knowledge, dissection principles and manual dexterity of all members of the team (otolaryngologists and neurosurgeons) are required throughout the whole procedure. In practical terms, and in most of our cases, this takes the form of '2 nostrils – four hands technique'[15] as a way of optimizing visualization and tissue handling. How does this work? This so-called '3–4 hands technique'[15] requires a good collaboration between two surgeons that should be perfectly tuned, one holding the endoscope as well as providing traction, and another handling two surgical instruments inside the surgical field. The surgeon could proceed performing a bimanual dissection while the colleague holds the endoscope moving it dynamically and is able to insert other surgical instruments. The bimanual dissection also proves to be time efficient. We found that our growth would not have been possible without the mutual support between the otolaryngologist and the neurosurgeon, reflected in the operating room but also transferred to the multidisciplinary skull base clinic and a joint learning curve. In practice, this means that most of the drilling of the skull base is performed by the otolaryngologist, with the neurosurgeon assisting and guiding, while most of the intradural dissection is performed by the neurosurgeon. The limits, however, are fluid, and in many cases we have found ourselves switching roles.

Direct view under high magnification

Anyone working with a bright modern endoscope using high-quality optics and a high-definition digital setup can testify to the excellent image projected (see Fig. 1 for an intraoperative snapshot of the software used to combine navigation scans and live video and Fig. 2). This image is shared by everyone in the operating room,

Table 1 Classification of endonasal approaches to the ventral skull base

Coronal plane		
Anterior coronal plane	Supraorbital approach: visualize orbital roof via removing medial orbital wall Transorbital approach: Intraconal lesions that are inferior and medial to the optic nerve	
Middle coronal plane	Infrapetrous approach: petrous apex, petroclival junction Suprapetrous approach: inferior and superior cavernous sinus; infratemporal/middle fossa	
Posterior coronal plane	From foramen magnum across the occipital condyle and hypoglossal canal to the jugular foramen	
Sagittal plane (Figure 8)		
Approach	Access to	Pathologies
Transfrontal	Frontal lobe	Encephaloceles/meningoceles, meningeomas
Transcribiform	Frontal lobe, olfactory nerve	Cerebrospinal fluid leaks, encephaloceles/meningoceles, benign intracranial tumours such as olfactory groove meningiomas and olfactory neuroblastomas
Transtuberculum/Transplanum	Optic chiasm, third ventricle	Extrasellar pituitary adenomas with suprasellar extension, meningiomas and select craniopharyngiomas
Transsellar	Pituitary gland, optic nerve, third ventricle	Pituitary adenomas and Rathke's cleft cysts
Transclival	Brainstem	Meningiomas, chordomas and chondrosarcomas
Transodontoid and foramen magnum	Brainstem, cervical spinal cord (C1, C2)	Rheumatoid arthritis pannus, meningiomas, chordomas and chondrosarcomas

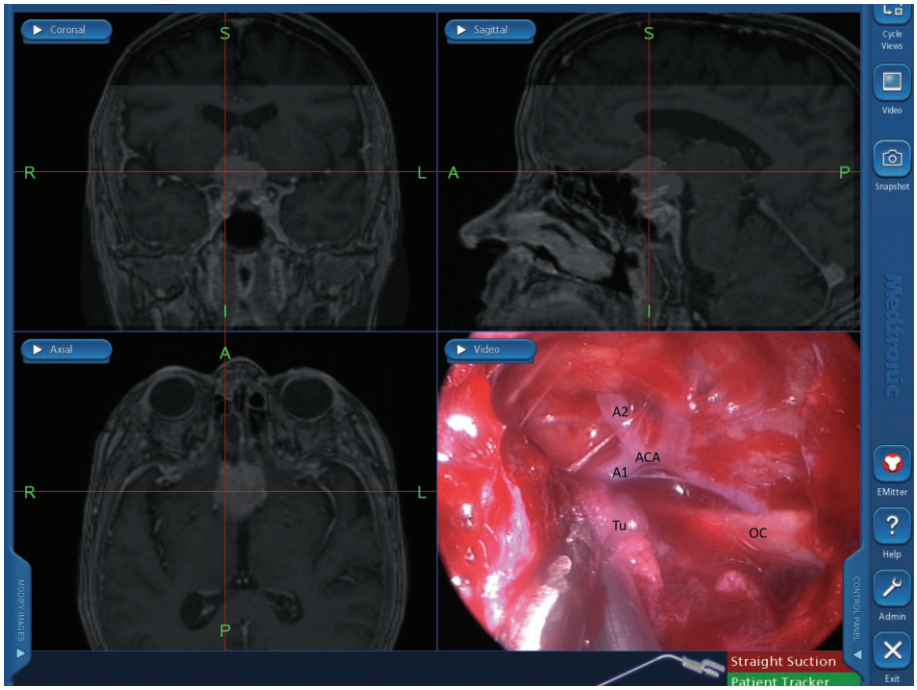

Fig. 1. Intra-operative snapshot of the software used to combine navigation scans and the live video images in a patient with a tuberculum sella meningioma, after drillout of the tuberculum sella and planum sphenoidale. The optic chiasma as well as the anterior cerebral arteries (A1 and A2) as well as the anterior communicating artery (ACA) and optic chiasm (OC) can be clearly visualized as the tumour (Tu) is being removed.

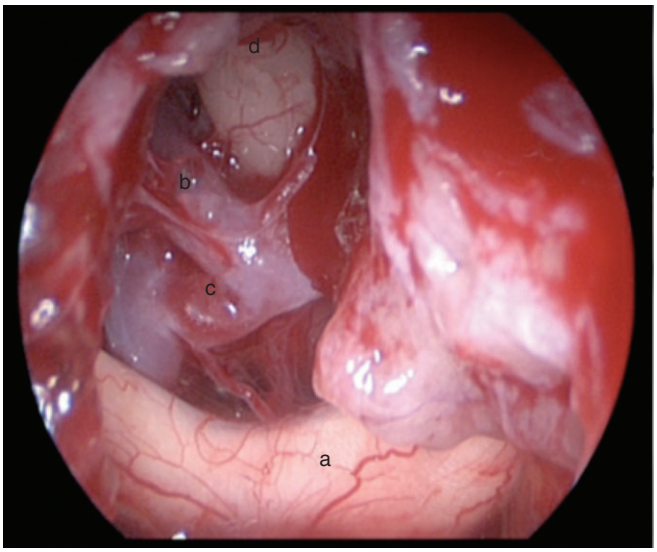

Fig. 2. Intra-operative photo after resecting a tuberculum sellae meningioma. The optic chiasm (a), anterior communicating artery (b), anterior cerebral artery (c) and cortex (d) are clearly visible.

facilitating communication between the team members and planning of surgery and anaesthesia.

Visualization under angle

Similar to holding a mirror, 30- and even 45-degree endoscopes can provide access to areas that would have been impossible to assess with the direct, straight view afforded by a microscope. This has proven especially helpful in assessing completeness of dissection and searching for tumour remnants in hidden angles, after the completion of tumour removal. Having said this, however, the extended view should be coupled with adequate access in order to manipulate instruments using a 3 or 4 hand technique – and visualization provided by the 30-degree endoscope should never be used as a substitute for adequate wide access.

Minimally invasive

This point is important, but we feel we should not take priority over radicality of dissection. Indeed, avoiding a craniotomy means that, in many cases, we can avoid the morbidity (scarring and blood loss) associated with the approach as well as the neurological sequelae associated with brain retraction. This results in many cases in faster recovery and reduced hospitalization.

Problems

Reconstruction of dural defects

Simple transphenoid endonasal approaches for hypophyseal tumour not extending above the diaphragm sellae, during which arachnoid is not breached, are associated with a low incidence of CSF leaks and do not routinely require extensive reconstruction. However, EEA produces routinely large dural defects, frequently communicating directly with areas of high flow leak, such as the third ventricle. Reconstruction of such large dural defects following EEA has been, and remains, a major challenge.

This was indeed the major limiting factor in the early days of EEAs – with rates of CSF leaks reported as high as 65%.[9]

Several techniques have been suggested to solve this problem, including a variety of grafts both autologous, heterologous or artificial, as well as vascularized pedicled flaps.

A significant progress has been the description of the Hadad–Bassagasteguy flap in 2005 which is essentially a mucoseptal flap. The mucoseptal flap is pedicled on the posterior septal artery, a branch of the sphenopalatine artery, and has been shown in

anatomical studies to be wide enough to cover skull base defects extending from the frontal sinuses to the planum sphenoidale and from orbit to orbit.[16,17] This technique produced a significant drop in CSF leaks after EEA, with the Pittsburgh group describing a reduction in the rate of CSF leaks from 40% and to 5%.[18] However, large dural defects produced by surgical corridors towards the tumour or the opening of the ventricles or cisterns are not the only factors to consider when deciding on reconstruction; other important issues involved include whether the patient has had prior transcranial surgery, prior radiation and prior intracranial infection. The above is codified in an intraoperative CSF leak grading system.[19] According to this system, grade 0 equals no CSF leak as confirmed by the vasalva manoeuvre, and grade 1 a small leak without obvious diaphragmatic defect; grade 2, moderate leak and grade 3, large diaphragmatic/dural defect which reaches over multiple surgical modules (cribriform plane, planum sphenoidale, tuberculum sellae, sella turcica, etc.).[19] Applying this grading system can lead to better assessment of the risk of delayed CSF leak and better tailoring of reconstruction methods as well as facilitate comparison between different centres and different reconstruction methods.

We use frequently inlay fascia lata grafts with onlay vascularized nasoseptal flap. We have found that vital to the success of this flap is the adequate lowering of the anterior wall of the sphenoid, to the level of its floor, so that the flap can be directly layered. Using different materials for its support, including merocel sponges and folley ballon catheters, we found the use of dissolvable spongistan glued with tissue col and supported with antibiotic – impregnated Vaseline gauze works best. We routinely insert merocel in both nasal cavities and advice patients to stay in bed for 4–5 days post-operatively, in the case of high flow leaks. We reserve the use of Lumbar drainage for recurrent CSF leaks and secondary repairs.

Bleeding

One of the biggest challenges in endoscopic skull base surgery is venous bleeding from the nasal cavity or the cavernous sinus impairing visualization, or potentially catastrophic arterial bleeding from the larger arteries including the internal carotids. We have found that the four-hand technique, working together, can be helpful in the visualization process, together with the use of bipolar diathermy, cauterizing of nasal mucosa, applying flowseal and being prepared for carotid bleeding (having an interventional radiologist on standby). Until now, we have not had to deal with carotid artery bleeding, although we routinely remove part of the bony cover of the carotid canal and we have dealt with a variety of tumours lateral to the carotid.

Limited space – 'sword fighting'

In the beginning of our learning curve, we often had the impression that working bimanually was restricted through the use of four instruments in such a small space (see Fig. 3); we have learned that even in small, paediatric noses, adequate bony exposure can facilitate intracranial dissection: complete removal of the anterior sphenoid wall, the posterior ethmoid cells, lateralizing of the inferior and middle turbinates, and (occasionally) removal of the middle turbinate can improve access significantly and reduce the 'sword fighting'.

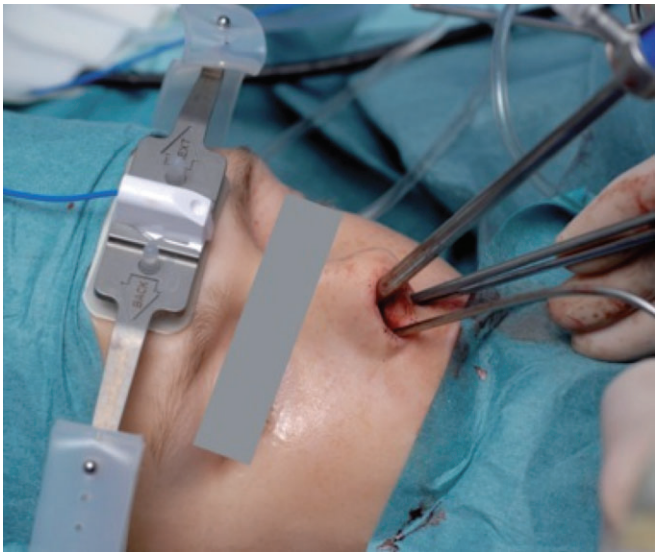

Fig. 3. Intra-operative endoscopic setting showing the 'four hands technique'.

Indications for EEA

Pituitary adenomas

The prevalence of pituitary adenomas is 16.7%; this figure is based on autopsy and radiology studies.[20] Pituitary adenomas consist of microadenomas (smaller than 1 cm) and macroadenomas (1 cm or bigger), secreting or non-secreting. Their management requires a multidisciplinary approach including a team of endocrinologist, otolaryngologist, neurosurgeon, ophthalmologist, neuroradiologist and pathologist.[14]

Treatment (medical or surgical) is required in order to normalize excess of hormone secretion, normalize pituitary function, eliminate mass effect, restore or preserve normal neurologic function (usually visual acuity or visual fields) as well as in order to achieve a complete pathologic diagnosis.[14] Fortunately, not all pituitary adenomas require surgical treatment.

The most common indication for surgery is acute visual acuity or loss of visual field, when the tumour is compressing the optic chiasm. Other indications for surgery include: non-functioning pituitary tumours, ACTH producing adenoma resulting in Cushing's disease, acromegaly resistant or when the patient will not tolerate medical treatment, thyroid-stimulating hormone-secreting adenomas. Prolactin-secreting tumours are almost always managed medically.

Pituitary adenomas are ideal tumours to excise via endoscopic transsphenoidal

The EEA[21] is the least traumatic route to the sella; it avoids visible scars, it provides excellent visualization of the pituitary gland and adjacent pathology, it offers a lower morbidity and mortality rate compared with transcranial procedures, and it requires only a brief hospital stay. Pituitary adenomas can expand suprasellar and may infiltrate the cavernous sinus compressing the carotid artery, which may require an EEA.

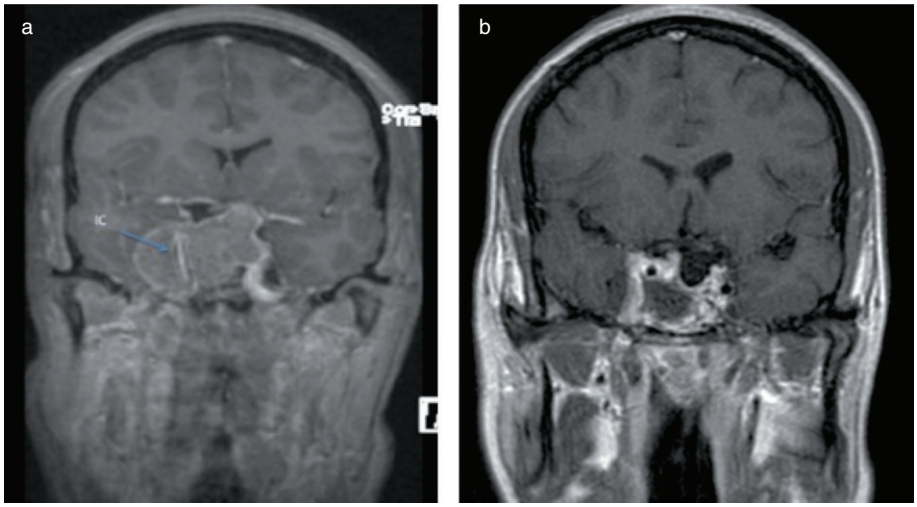

Fig. 4. 21-year-old patient with a large suprasellar pituitary adenoma invading the cavernous sinus: Notice the compressed right internal carotid artery (IC) with reduced flow (a), and MRI scan 2 days postoperatively, showing complete removal of the pituitary adenoma (b). Dissolvable material with air is seen in the empty sella cavity.

Illustrative case

A 21-year-old student came to our clinic with persistent headache for which she used homeopathic medicine for 9 months with limited improvement. Two weeks before imaging (shown below in Fig. 4a), she developed bitemporal hemianopsia. The lesion was removed via EEA: the posterior ethmoids as well as the sphenoid sinus were fully opened. The posterior maxillary wall and the pterygopalatine fossa were exposed, providing in this way adequate lateral access to the sella. The whole tumour including its paracarotid component was clearly visualized and removed, with minimal bleeding. (post-operative MRI scan shown in Fig. 4b). For reconstruction, a mucoseptal flap was used. The pathological diagnosis of the tumour was a non-secreting pituitary adenoma. She regained full vision and her headache resolved completely.

Although in 96% of pituitary tumours the transphenoid route is the preferred way,[22] the transcranial route cannot be completely abandoned. Pituitary adenomas can invade intracranially, and with extensive intracranial involvement in some cases it is not possible to remove them completely via EEA. An example is a dumbell adenoma, where the intracranial extension is separated from the intrasellar portion by a narrow neck in which case a transcranial route is preferred.[14,23]

Skull base meningiomas

Since the advent of endoscopic endonasal skull base surgery, skull base meningiomas have become an increasing focus of ENT and neurosurgeons. Approaching the tumour from below allows early devascularization of the meningeal blood supply without brain retraction and minimizing manipulation of the optic nerves and optic chiasm.

Outcomes in all meningiomata surgery (including convexity meningiomata) are graded via the Simpson grading system.[22] A Simpson grade 1 (in toto resection tumour including the dura tail) or 2 (in toto resection tumour and coagulation of dura tail) is the goal of surgery. Recurrence rate in such resections is approximately 9–15%, although some surgeons prefer to describe percentage of resection, which makes comparison more difficult.

Until now, most published data we have on skull base meningiomas resected via EEA are tuberculum sellae meningioma (TSM) and olfactory groove meningiomas (OGM).

TSM usually arises in the midline from the region of the tuberculum sellae and planum sphenoidale. As the tumour enlarges, it compresses the optic nerves and chiasm. OGM arising from the olfactory groove or cribriform plate may occasionally produce frontal lobe syndrome symptoms. Reported Simpson grade 1 or 2 resections vary between 77.8% and 92% for TSM and 66.7% to 100% for endonasally removed OGM, while almost all patients with vision loss showed post-operatively improved or resolution of visual function.[18,24–28] These results compare favourably with most published series of transcranial resection.

Illustrative case

A 52-year-old lady was admitted in our hospital with a frontal syndrome and loss of smell. The symptoms were caused by a large olfactory meningioma with oedema of the frontal lobe (see MRI scans in Fig. 5a,b). The olfactory meningioma was resected via EEA: A complete ethmoidectomy and sphenoidectomy was followed by an endoscopic modified Lothrop (Draf 3 frontal sinus median drainage procedure), thus providing access to the whole cribriform plate, from the frontal to the sphenoid sinus. The anterior and posterior ethmoid arteries were ligated and the anterior skull base was removed, from medial to medial orbit. The intranasal component of the tumour was then removed followed by intradural dissection of the intracranial part, using Cuser for initial debulking of the tumour core and then bimanual dissection of its remnants. Reconstruction was performed using a mucoseptal flap and fascia lata. Resection was Grade 1, without any complications occurring. Over the next months, the oedema of the frontal lobe as well as the frontal syndrome itself resolved.

Cranial nerve lesions

At the skull base, we also find pure brain tumours. Optic pathway and hypothalamic gliomas grow along the skull base, causing proptosis and visual acuity and endocrinologic dysfunction and are

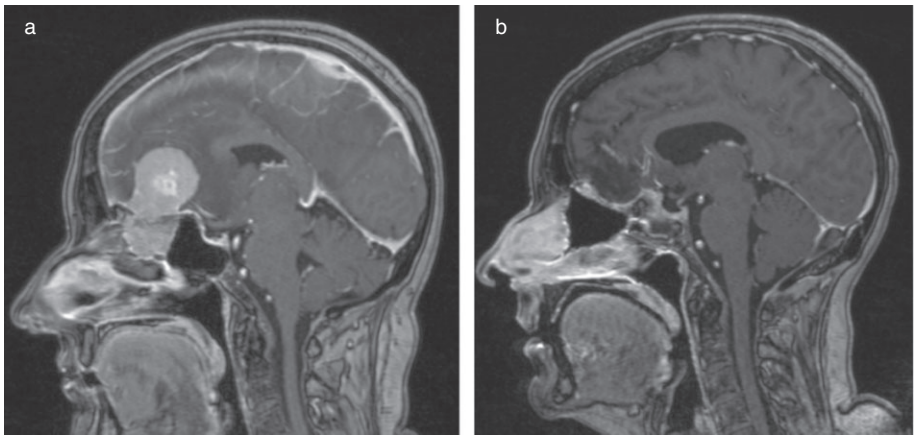

Fig. 5. MRI scan of a 52-year-old patient depicting a large olfactory meningioma with intracranial extension (a), and post-operative scan from the same patient, showing the complete removal of the tumour and good adhesion and placing of the nasoseptal flap (b).

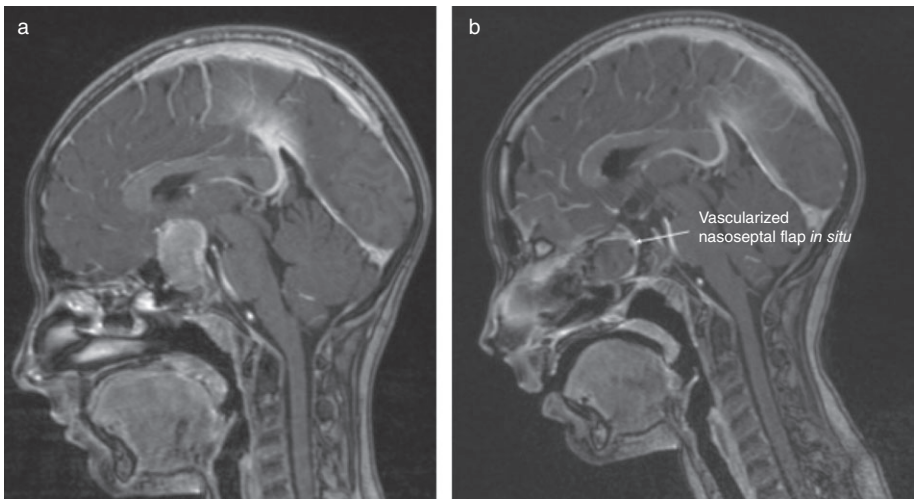

Fig. 6. Young patient with a large craniapharyngioma compressing the pituitary gland and the optic chiasm (a), and immediate post-operative MRI scan showing a grade 1 removal of the craniopharyngioma (b). Note the enhancing (vascularized) nasoseptal flap used for reconstruction.

accessible via EEA.[14] These tumours comprise 5% of paediatric intracranial tumours, though it also occurs in the adult population. It is described that in 33% of the children it is a part of neurofibromatosis type 1.[29] Neurofibromatosis is a common genetic disorder, with a predisposition to nerve sheath tumours. We know that in children with neurofibromatosis type 1, this particular tumour growth is less common than in children without. For that reason, the diagnosis of neurofibromatosis in children with an optic pathway and hypothalamic glioma is important. Surgical debulking (due to its location to achieve complete removal is impossible) is only advisable in tumour progression with mass effect and progressive hydrocephalus.[30]

The use of the endonasal approach towards this tumour is rather limited. It can be a feasible option to gain a biopsy for children who are not yet diagnosed with neurofibromatosis type 1. Chemotherapy remains the treatment of first choice due to the location of the tumour.[31]

Another type of cranial nerve lesion are schwannomas. Schwannomas are benign, accounting for 7% of intracranial tumours.[32] Treatment is only necessary in case of symptomatic lesions which can only be surgically resected. The largest study group is reported by Kassam *et al*.[33] Consisting of resection of schwannomas originating from the trigeminal nerve (second preferred location of schwannomas) located in the Meckel's cave, complete removal was achieved in 83.1%. Furthermore described are complete removal of schwannomas originating from the olfactory nerve, but only reported as case studies.[34]

Craniopharyngiomas

In 2010, a 13-year-old girl came to our combined clinic with a growth delay due to GH deficiency, resulting from the presence of a suprasellar lesion (Fig. 6a). Through an extended transplanum/transtuberculum approach, a complete, including the tumour capsule, resection of the tumour was performed. The reconstruction of the skull base was done using fascia lata and the nasoseptal flap. The boy did not have a CSF leak or any other complications after surgery.

The incidence of craniopharyngiomas is 0.13 per 100 000 per year favouring 5–14 years old (adamantinomatous type) and adults of ages 50–74 (papillary type), accounting for 5.6–15% of intracranial tumours in children.[35] Craniopharyngiomas tend to adhere and infiltrate surrounding structures despite their benign histology.

Tumours can be found in the sellar and suprasellar region, and they can compress the optic nerves/chiasm, pituitary stalk and gland, floor of the third ventricle, hypothalamus, and cerebral vasculature of the circle of Willis.

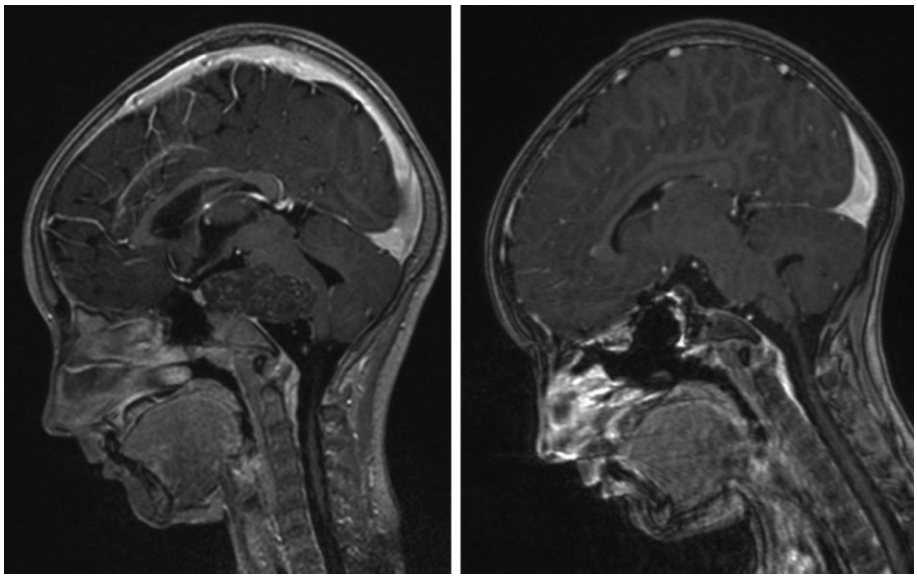

Fig. 7. 10-year-old girl with a large process in the posterior fossa, originating from the clivus and compressing the brain stem (a), and immediate post-operative MRI scan showing a complete removal of the anterior wall of the sella face and the clivus between the two carotids (b).

EEAs for craniopharyngiomas have enabled safe and effective treatment of these lesions by directly accessing the suprasellar space via a transtubercular/transplanum approach, which before was not a possibility in patient with normal pituitary function because you had to traverse the sella.[14] Adjuvant radiotherapy with stereotactic radiosurgery or conventional external beam radiotherapy appears to have resulted in better long-term control rates, reducing the recurrence/progression rates after subtotal removal ranging from 0% to 30% (mean 17.2%).[36]

Published results for EEA removing craniopharyngiomas showed a gross total removement/near total removement (GTR/NTR equals removing more than 95% of the tumour) in 77.9% of cases, and subtotal removement (equals more than 70% removal) of an extra 18.2% of cases. Comparing these data to transcranial series seems at least equivalent with GTR rates ranging between 9.5% and 90%.[36–39]

Chordomas

Chordomas are rare and considered a low-grade malignancy, although metastatic dissemination is possible (10–20%) to lung, bone, liver and lymph node, as well as seeding along the surgical pathway. They are located at the end of the spinal axis and 35% of chordomas involve the clivus. The reported 5-year survival rate in young patients is 70–75% and in older patients 30%.[40,41] In the last decade, this tumour is dissected via EEA. Until now, no new post-operative cranial nerve or neurological deficits and no surgical mortality are reported following resection. Although reported results are scarce and regardless of which surgical approach is used, total removal is achieved in only 49.2–79% of reported cases[42]; often, a second operation was needed to remove residual tumour.[43–46]

Combination of radical surgery and high-dose radiation therapy is regarded as the best treatment, and often in the case of subtotal removal, gamma knife stereotactical radiosurgery is given afterwards.

Illustrative case

A 10-year-old girl presented with symptoms of nausea, vomiting, bilateral abducens palsy (more prominent on the right side) and walking difficulties. On the MRI there was a large process in the posterior fossa, originating from the clivus and compressing the brain stem (preoperative and post-operative MRI scan, Fig. 7).

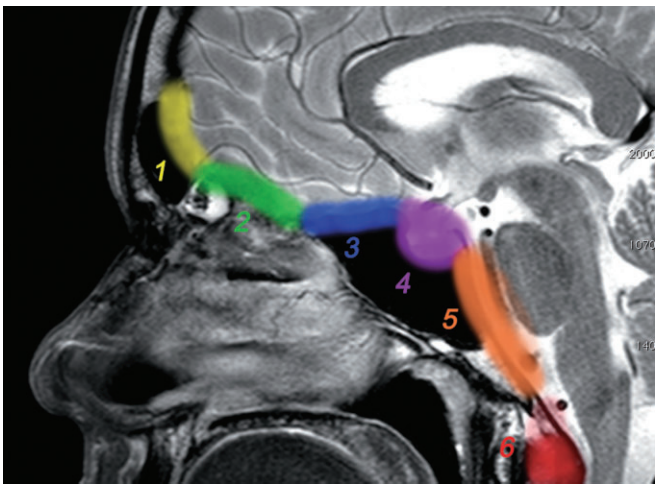

Fig. 8. Sagittal plane approaches schematic depicted on an MRI scan of the skull base. (1) transfrontal, (2) transcribriform, (3) transtuberculum/transplanum, (4) transsellar, (5) transclival, and (6) transodontoid and foramen magnum.

An EEA was performed (transclivus approach) with complete removal of the anterior wall of the sella face and the clivus between the two carotids. The tumour was macroscopically almost completely removed, with a minimal remnant of tumour capsule left *in situ* as it was adherent on the right carotid. Reconstruction was with fascia lata and nasoseptal flap. There were no complications or CSF leak post-operatively. Diplopia resolved after a few weeks, and on an MRI performed post-operatively there were no macroscopic tumour remnants.

In view however of the operative findings, the young age of the patient and the tumour histology, it was decided to proceed with post-operative radiotherapy.

Discussion

EEA is a feasible option to treat skull base tumours. Main limitations to consider are location of the skull base lesions and its surrounding neurovascular structures. For example,in a clival chordoma growing below the optic nerve, an EEA is favoured from a transcranial approach and vice versa. An experienced surgical team in endoscopic skull base surgery is required to not only understand the anatomical structures presented through the endoscope but also to work as a true team in order to gain optimal results. And prior high rates of complications such as cerebrospinal leaks are now made acceptable by new reconstruction methods.

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