The transnasal approach to the skull base. From sinus surgery to skull base surgery

Abstract

The indications for endonasal endoscopic approaches to diseases of the skull base and its adjacent structures have expanded considerably during the last decades. This is not only due to improved technical possibilities such as intraoperative navigation, the development of specialized instruments, and the compilation of anatomical studies from the endoscopic perspective but also related to the accumulating experience with endoscopic procedures of the skull base by multidisciplinary centers. Endoscopic endonasal operations permit new approaches to deeply seated lesions and are characterized by a reduced manipulation of neurovascular structures and brain parenchyma while at the same time providing improved visualization. They reduce the trauma caused by the approach, avoid skin incisions and minimize the surgical morbidity. Transnasal endoscopic procedures for the closure of small and large skull base defects have proven to be reliable and more successful than operations with craniotomies. The development of new local and regional vascularized flaps like the Hadad-flap have contributed to this. These reconstructive techniques are furthermore effectively utilized in tumor surgery in this region. This review delineates the classification of expanded endonasal approaches in detail. They provide access to lesions of the anterior, middle and partly also to the posterior cranial fossa. Successful management of these complex procedures requires a close interdisciplinary collaboration as well as continuous education and training of all team members.

Keywords: endoscopic skull base surgery, skull base defect, skull base neoplasm, CSF-leak, reconstruction

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1. Introduction

The last two decades have seen a continuous increase in the application and acceptance of endoscopic endonasal surgical techniques for the treatment of skull base defects. But also neoplasms of the paranasal sinuses, the skull base, and adjacent structures have become treatable using such techniques. This has become feasible on the basis of detailed anatomical studies of the skull base from an endoscopic perspective – that is partially very different from the classical point of view. Furthermore, the advances and the consequent use of intraoperative navigation systems, as well as the development of specialized instruments for endoscopic use have furthered this development and enabled skull base surgeons to reach even deeply seated lesions with minimized trauma.

Transnasal endoscopic techniques possess an invaluable advantage over the unarmed eye and the microscope – they allow the view around the corner. Therefore, the approaches to anatomic regions of the skull base don't have to be straight-line. This introduces completely new pathways to skull base surgeons. But this also necessitates rethinking in relation to the anatomy because familiar structures have to be recognized again from the new perspective although the topographical context hasn't changed.

The form of the surgical operative corridors is in a way turned upside down. While the width of traditional approaches is typically tapering from the outside to the inside, the narrowest point of endonasal approaches is usually the nostril and widens markedly from there into actual surgical field.

The feasibility of endoscopic approaches is mainly determined by the topographical relation of critical anatomical structures to the surgical corridors. The associated risks of these new methods are therefore less dependent on the size of the targeted lesion but more on the neurovascular structures along the path of the approach.

The safety and feasibility of expanded endonasal approaches is well established in the meantime and documented in several publications [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11]. Currently, expanded endonasal approaches allow to address lesions of the anterior, medial and posterior cranial fossa [12], [13].

The accumulating experience that has been gained in different specialized centers worldwide make expanded

endonasal approaches to the skull base important and critical tools for skull base and sinus surgeons.
Important advantages of these approaches in relation to classical surgical techniques and approaches are the access to deeply seated lesions, a more direct exposition of the midline, reduced trauma to brain parenchyma, the lack of manipulation to neurovascular structures, rapid decompression of the optical apparatus, and early devascularization of neoplasms [5], [6], [7], [14].
Studies documenting that the endoscopic methods produce results comparable to those of open surgical approaches for tumors of the paranasal sinuses, the sella, and the skull base [2], [6], [9], [10], [14], [15], [16] have proven instrumental for the acceptance of expanded endonasal approaches. The finding that piecemeal resection of malignant neoplasms doesn't compromise the oncological results as long as the completeness of the ablation is proven by histological evaluation of the resection borders is also important in this context [17].
Additional advantages of the endoscopic approaches are the shorter duration of the operations (in some cases), a decreased hospital stay, and improved quality of life of the patients, as wells as the lack of external cuts [11].
It shouldn't be assumed that the limits of the possibilities of expanded endonasal approaches have been reached yet. Neither the entity of tumors, nor their size, vascularization, form, structure, or the extradural locoregional extension, invasion of vessels, meningeal infiltration or intradural growth are general contraindications for endoscopic endonasal approaches. It are rather the following considerations that determine the selection of endonasal endoscopic or traditional open surgical approaches: The relation of the lesion to critical neurovascular structures – endoscopic approaches are especially appropriate if the lesions are bordering to neurovascular structures since they allow to reach such neoplasms with minimal manipulation to them. Furthermore, the experience of the surgical team and the technical prerequisites are crucial for optimal surgical results when using these techniques because good visualization, the feasibility to attain hemostasis [18], as well as the need to be able to handle vascular complications and to perform appropriate reconstruction are mandatory [19], [20], [21].

2. Techniques & execution

2.1 Principles of endoscopic endonasal skull base surgery

2.1.1 Bilateral exposition

To allow three- or four-hand techniques – that is the simultaneous working of two surgeons – a binarial approach is required in most cases. This facilitates bimanual dissection because it generates the room necessary for the manipulation of instruments and dynamic movement of the endoscopes. In many cases the binarial approach also improves the angle for preparation. The surgical corridor can be further enlarged when the inferior and/or middle turbinates are lateralized or (partially) removed. These techniques can expand the access to the posterior and cranial parts of the nose and the skull base markedly. The significance of these procedures is the better exposition of anatomical landmarks, the avoidance of soiling of the endoscope and restriction by multiple instruments – thus the warranty of an unobstructed view on the surgical field. The use of fixed endoscope holders has not proven useful to date since it is the movement of the endoscope that generates the "pseudo-three-dimensional" view.
The sphenoid sinuses are opened widely on both sides and the approach is maximized laterally up to the level of pterygoid plates and the lateral wall of the sphenoid, cranially enlarged to the planum shenoidale and caudally to the floor of the sphenoid sinus. To optimize bilateral manipulation and visualization partial removal of the posterior nasal septum is performed.

2.1.2 Tumor resection

The principles of tumor resection don't differ from microscopic techniques. Successively, internal debulking, extracapsular dissection of neurovascular structures, and coagulation and resection of the capsule using bimanual techniques that allow for tactile depth perception are performed. The methods that are used for tumor debulking usually depend on its consistency – bimanual suction, ultrasonic aspiration, or piecemeal resection with cutting instruments can all be used.

2.2 Endoscopic reconstruction of skull base defects

Cerebrospinal fluid (CSF) leaks are a dangerous situation due to their potentially catastrophical consequences like ascending meningitis, intracranial abscesses, neurological deficits and death. This explains why attempts to identify and close the underlying skull base defects have been undertaken early in the history of otorhinolaryngology and neurosurgery.
After the first description of a CSF leak by Charles Miller in the year 1826 [22] and the designation of the term "cerebrospinal rhinorrhea" by Sir St. C. Thomson [23], it was Walter Dandy who first reported of the successful closure rhinoliquorrhea in 1926 [24]. He performed a frontal craniotomy and used fascia lata to occlude the defect. In 1948, the Swede Dohlman used a nasoseptal flap to cover a defect in the ethmoidal roof [25] but the pioneer of an endonasal approach was the Viennese Oskar Hirsch performing a transeptal approach to the sphenoid sinus where he closed a defect [26]. But it took until the 1990s of the last century before a trend towards strictly endoscopic endonasal approaches could be observed in the literature [27], [28]. Until then operations for the management of rhinoliquorrhea were a domain of neurosurgeons. Success rates between 60% and 80% [29], [30] were the norm and problems occurring due to

frontal lobe retraction and anosmia were quite common [31], [32], [33].

In the following years the surgeons' expertise but also the instruments as well as technical aids (such as intraoperative surgical navigation systems) improved markedly. This not only lead to much broader indications for endonasal approaches for the treatment of rhinoliquorrhea, but also improved the success rates after primary closure up to 88% to 94% [30], [34], [35], [36], [37], [38], [39].

To confirm the diagnosis of rhinoliquorrhea preoperatively, nasal secretions can be collected and analyzed. The measurement of beta-trace protein is the gold-standard in this context [40]. This protein is the brain isoform of Prostaglandin D2-synthetase and highly specific for CSF. This method is not only more cost-efficient and faster than the determination of beta2-transferrin [41], [42] but also more reliable [43]. The use of glucose testing for suspected CSF-leakage is no longer in keeping with the times because of its unreliability [40], [44].

A very useful method to identify the localization of skull base defects intraoperatively is the intrathecal application of fluorescein [27]. In selected cases it can also be used for the diagnosis of rhinoliquorrhea. The technique is based on the fact that CSF can be recognized by its neon-green fluorescing color even in very low concentrations of fluorescein (up to 1:10 millions). This effect can be further intensified by a blue light blocking filter thus facilitating the identification of the exact localization of the lesion. Furthermore, this technique allows for the identification of insufficiently healed scars that don't lead to CSF-leaks but may predispose to ascending infections since fluorescein can impregnate and color these. Fluorescein can also be used to test the tightness of closures intraoperatively [39], [45].

Since the usage of fluorescein for these indications is off-label, informed consent from patients must always be obtained. Decades of experience with this utilization of fluorescein have demonstrated that this procedure has few side effects when used correctly [27], [37], [39], [45], [46], [47].

A sterile, pyrogen-free, 5% (50 mg/ml) aequeous sodium fluorescein solution without the addition of preservatives and stabilizers is applied by standard lumbar puncture. The total dose recommended is 0.005 to 0.01 ml per kg body weight with a maximum volume of 1 ml [39], [45], [47]. It should be applied a few hours or on the evening before surgery.

2.2.1 Surgical techniques

A multitude of different materials for the closure of skull base defects are available. Most autologous grafts are well suited. The use of autologous materials circumvents all potential dangers of allogenic and xenogenic transplants such as prion diseases [48], [49], [50]. The available literature doesn't show superiority of a specific material.

Many surgeons prefer fascia lata because of its ease of explantation and the relatively big size of transplants that can be obtained. It can be combined with other materials such as cartilage and fat, and its consistency is similar to dura mater. Temporal fascia can also be used although it is thinner than fascia lata. To improve the stability, cartilage obtained from the nasal septum or the ear concha can be added. Bone transplants should be avoided in endoscopic surgery because they are absorbed relatively quickly [40]. Fat can be removed paraumbilically, and can be utilized for obliteration in combination with other materials or as a fat-plug [50].

When there are reasons that preclude the use of autologous transplants, several alloplastic materials can be applied [51], [52], [53], [54], [55]. A uniform opinion on their suitability does not exist [40].

Most authors prefer to stabilize transplants and flaps by applying fibrin glue [39], [40]. Nevertheless, some papers also report good result without its use [35], [38].

2.2.2 Techniques

Smaller defects can be covered with free mucosal grafts or free flaps of mucoperichondrium or mucoperiostium that can be harvested from the nasal septum or the turbinates [56], [57], [58], [59].

It is recommended for all kinds of defect closures – with the exception of underlay techniques – that the area where the grafts or flaps are placed should be completely free of mucosa to avoid the formation of mucoceles.

Underlay

For underlay techniques the graft is placed between dura mater and skull base. It is crucial to create sufficient overlap to obtain impermeability and to compensate for the postoperative shrinkage of the transplant.

Overlay

For this technique the graft is placed between the bone and the mucosa. Frequently, it is combined with underlay techniques as a "sandwich-technique" [36], [52], [53], [60].

The use of fat-plugs that are inserted through the defect and expand above the dura can also be recommended for endoscopic endonasal surgery. They can used to stop CSF-flow while additional measures such as the of overlays or mucoperiosteal flaps are prepared. These fat-plugs can also be stabilized by the addition or cartilage or fascia into the defect [50].

In the case of meningoencephaloceles where the content of the hernia can't be repositioned up to level of the defect, the hernia should be resected since a reliable closure won't be feasible otherwise. It is obligatory to ensure that the cele doesn't contain vital or relevant neural structures beforehand by adequate imaging studies [61], [62], [63], [64], [65], [66].

2.2.3 Lumbar drainage

The routine installation of lumbar drainages is not recommended since no obvious advantage could documented in the literature [40]. This doesn't preclude their use in individual cases – especially because the whole spectrum – from no lumbar drainages [67] to 100% [57], [68] and the whole spectrum in between these extremes [69], [70], [71] can be found in publications – without obvious effects on the rate of success.

2.2.4 Perioperative use of antibiotics

Approximately 2% of all extended endonasal skull base procedures are complicated by postoperative bacterial meningitis [17], [72]. This means that the rate of infection is rather lower than for conventional skull base procedures [73], [74] although this could also be related to the recommendation of almost all centers to use broad-spectrum antibiotics perioperatively in extended endonasal skull base procedures [40], [73], [74], [75], [76].
Monotherapy with broad-spectrum cephalosporins (e.g. Cefazolin or Ceftazidim) is the standard. In cases with augmented risk of infection dual therapy with Ceftazidim and Amikazin has been suggested [72]. Antibiotic treatment should be initiated at least 30 minutes before the incision and continued for the duration of the nasal packing but at least for 48 hours [40], [74], [77].

2.2.5 Postoperative treatment

The same principles for nasal packing are valid for endonasal skull base surgery as for endoscopic sinus surgery [78]. As a basic principle packings with a smooth surface are preferable to avoid mucosal injury and to prevent problems in wound healing. A particularity is the use of local vascularized flaps (see below) because a sufficient adherence of the flap to defect is necessary. Here, balloon catheters or inflatable packings can be utilized [79], [80]. Mostly nasal packings are left in place for an extended duration after skull base operations [39] although systematic investigations of this recommendation are lacking [40].
The same is true for the question of the duration of bed rest and hospitalization. They should always depend on the individual course of the disease and the extent of the procedure albeit the last years have seen a tendency for reduction in most centers [40].
As a basic principle, lifting of heavy objects, physical effort, forward bending, and nose blowing should be avoided in reconvalescence, although no systematic studies on these aspects exist.

2.2.6 Prognosis and complications

A systematic analysis of the literature [40] came to the result that (in a widely variable observation period from 1–312 months) in 40 of 769 (5.2%) of patients that had endoscopic skull base surgery complications occurred. These were one mucocele, synechias (n = 8), fever (n = 2), headaches (n = 1), transient diabetes insipidus (n = 2), pneumocephalus (n = 3), hydrocephalus (n = 4), meningitis (n = 13) and one patient deceased due to hypertensive crisis and subarachnoidal bleeding, and additional complications [81].
The same paper states that recurrent CSF-leaks occurred in 122 of 1,213 (10.9%) patients [40]. These were noted between the second day after surgery and 18 months later. Interestingly, many of these recurrences were found in patients with defects in the sphenoid sinus. This points to the difficulty of achieving sufficient closure in this region – especially in the lateral aspects of the sphenoid sinus and the area of the Sternberg-canal, where meningo-encephaloceles can occur [66].

3. Techniques for reconstruction in endonasal skull base surgery

Not long ago, the well-known skull base surgeon, Prof. Paolo Cappabianca from Naples said in his lecture about the development of extended endonasal skull base surgery (Annual Meeting of the DGSB 2010) that "reconstruction is more problematic than resection". Therefore it comes at no surprise that it were the advantages in reconstructive techniques for the closure of surgically induced defects of the skull base that enabled the important progress in endonasal skull base surgery.
The ultimate goals of all techniques for reconstruction in the region of the skull base are the stable separation between the nose and the cranial cavity, the protection of neurovascular structures, the conservation or reconstruction of cosmesis, the preservation or reconstitution of function and the avoidance of dead spaces. In this respect, the separation of nasal and cranial cavity is of utmost importance because it prevents postoperative CSF leaks, pneumocephalus, and intracranial infections, and protects cranial nerves and large vessels from infection and trauma. The effects of postoperative radiotherapy also have to be considered.
Although a number of different techniques have been used successfully [19], [82], [83], [84] to endoscopically treat CSF-leaks after trauma, iatrogenic injury, or in spontaneous rhinoliquorrhea, these methods have proven insufficient to reconstruct the large defects in extended endonasal skull base surgery. It was not until local vascularized flaps – in particular the Hadad-Bassagasteguy-flap [85] (Hadad-flap) – were developed that the rate of postoperative CSF leaks even after expanded resections at the skull base could be reduced to below 5% [20], [86]. This technique is thus as successful as traditional surgical methods [79]. In the meantime a number of variations of this flap and additional pedicled flaps have been developed to comply with different surgical situations. It should nevertheless be decided before the operation which type of reconstruction will be used because many of the flaps can't be raised once the resection has been

Table 1: Techniques of reconstruction for skull base defects (modified after Lund [40])

Localization	Size of defect	Free tissue	
		Underlay/Overlay/Sandwich	Fat plug
Anterior SB	Small	+	(+)
	Large	(+)	(+)
Middle SB	Small	+	(+)
	Large	(+)	(+)
Sella	Small	+	+
	Large	(+)	(+)
Posterior SB	Small	+	+
	Large	(+)	(+)
CSF flow	Low	+	+
	High	ø	(+)
ICA exposition		(+)	(+)
Radiotherapy		(+)	(+)

Localization	Size of defect	Local flap		
		Hadad-flap	Pedicled inferior turbinate	Pedicled middle turbinate
Anterior SB	Small	(+)	ø	+
	Large	+	ø	ø
Middle SB	Small	(+)	ø	ø
	Large	+	ø	ø
Sella	Small	(+)	+	+
	Large	+	ø	ø
Posterior SB	Small	(+)	+	ø
	Large	+	ø	ø
CSF flow	Low	(+)	(+)	(+)
	High	+	+	+
ICA exposition		+	(+)	(+)
Radiotherapy		+	+	+

Localization	Size of defect	Regional flap		
		Oliver palate island	Transpterygoid temporoparietal fascia	Transfrontal pericranial
Anterior SB	Small	(+)	ø	(+)
	Large	+	ø	+
Middle SB	Small	(+)	(+)	ø
	Large	+	+	ø
Sella	Small	(+)	(+)	ø
	Large	+	+	ø
Posterior SB	Small	(+)	(+)	ø
	Large	+	+	ø
CSF flow	Low	(+)	(+)	(+)
	High	+	+	+
ICA exposition		+	+	(+)
Radiotherapy		+	+	+

Abbreviations: SB = skull base, ICA = Internal carotid artery, + = recommended, (+) = possible, ø = not recommended

performed (Table 1). For large defects even combinations of different flaps can be used.
The stabilization of defects with (autologous) cartilage or bone transplants is suggested by some authors [87], [88], [89] but doesn't seem to be necessary since herniations were not observed even in large series [15], [79], [86], [90], [91].
Generally, it is also feasible to utilize distant flaps with microvascular anastomoses but in most cases this is not

compatible with exclusive endonasal approaches due to technical reasons.

Not all endonasal skull base operations lead to large defects and therefore reconstruction with free mucosal grafts still has its place. In trans-sellar pituitary surgery good results have been demonstrated with free mucosal flaps [92], [93]. Furthermore, the expenditure of time to prepare pedicled flaps can be quite high and there is also a risk to induce additional postoperative morbidity by using these techniques.

3.1 Hadad-Bassagasteguy-flap

The “Hadad-flap” is a pedicled, vascularized flap of the mucoperichondrium and periosteum of the nasal septum. Its vascularization is provided by the nasoseptal artery that stems from branches of the sphenopalatine artery and runs above the choana to the septum.

Its relatively long pedicle develops by placing horizontal incisions between the lower aspect of the sphenoid ostium (cranial boundary) and directly at the edge of the choana (caudal boundary) – this is exactly the region where the artery runs. From there, incisions are placed to the nasal septum in a rostral direction. The width, length, and form of the flap can be adapted to the size of the expected defect. Cranially, a distance of approximately 1–2 cm to the insertion of the septum at skull base should be kept to avoid damage to the olfactory epithelium. The caudal limit is typically the transition to the maxilla. The maximal rostral extension is the mucocutaneous junction in the nasal vestibule. Similar to septoplasty, the flap is mobilized by subperichondrial preparation. It can then be placed in the nasopharynx to reduce blockage by the flap during the following steps of the operation. To facilitate the identification of the mucosal surface, the surface of the flap can be marked with ink.

When the flap is placed over the defect, it is crucial to ensure complete attachment of its base to the surrounding area. The correct placement of nasal packings is very important in this respect. Furthermore, balloon catheters can be helpful to maintain attachment of the flap to its base [79], [80]. The area of the Hadad-flap is stated to be approximately 25 cm^2 [94], which – in addition to its relatively long pedicle and its good maneuverability, enables the use of this flap to cover defects of the anterior skull base, the planum, the sella region, and the clivus. It is also possible to lift simultaneous Hadad-flaps on both sides which doubles the usable area [95]. Postoperatively, the quality of the reconstruction and the perfusion of the flap can be controlled by imaging studies [96]. Even the re-use of Hadad-flaps in revision surgery has been described [97] and is feasible in our hands.

The Hadad-flap has proven to be the “work-horse” for reconstruction in extended endonasal skull base surgery because of its versatility, the relative ease of preparation of the flap, its large surface, and its mobility. Loss of the flap is rarely observed and at the most seen in patients where the region of the pedicle was subject to radiation therapy [86], [91]. Contraindications for these flaps are tumors that infiltrate the nasal septum, the pterygoid fossa, or the anterior wall of the sphenoid sinus. Furthermore, large septal defects (such as those observed sometimes after transseptal pituitary surgery) and previous operations where major parts of the anterior wall of the sphenoid had been removed are problems that make the use the Hadad flap impossible.

3.2 Posterior pedicled inferior turbinate flap

The lower turbinate can also used to gain a vascularized flap for reconstruction. Admittedly, it is a relatively slim and long flap (area approx. 4.5 cm^2 [98]) with a short pedicle. Therefore it is mainly used for smaller defects in dorsal regions such as the clivus or the sella. It is based on an artery that stems from a postero-lateral branch of the sphenopalatine artery that enters the turbinate from a dorso-cranial direction. The flap is prepared by placing parallel incisions at the cranial and caudal aspects that are joined by a vertical cut along the head of the turbinate and elevation of the mucoperiosteum from the bone.

3.3 Posterior pedicled middle turbinate flap

Another branch of the sphenopalatine artery that enters the middle turbinate from a dorsal direction provides the vascularization of this flap. Although its area is slightly larger than that of the previously described flap (5.6 cm^2 [99]), its preparation can be tedious because of the difficult separation of mucoperiosteum and bone. It can utilized to close defects of the cribriform plate, the fovea ethmoidalis, the planum sphenoidale or the sella.

3.4 Transpterygoid transposition of temporoparietal fascia flap

This flap is well known from other ENT-operations and is obtained from the temporal region where its blood supply stems from the superficial temporal artery. In this case it should be dissected into an inferior direction up to the lateral aspects of the zygomatic arch. To allow transposition into the nasal cavity a transpterygoid corridor has to be prepared [100]. This can be achieved by opening the pterygoid fossa through the dorsal wall of the maxillary sinus, ligation of the sphenopalatine artery and further removal of bone of the dorsal and lateral wall of the maxillary sinus to create a wide opening into the infratemporal fossa. The anterior aspects of the pterygoid plates have to be reduced with a drill to expose the region even wider. The access can now be created by elevating the temporal muscle from the lateral wall of the orbit in a caudal direction and then into the direction of the temporal fossa and further into the infratemporal fossa. The access can be further enlarged using dilators (e.g. dilators for percutaneous tracheotomy). The flap can then be fixed with a guide wire and pulled through. The large area of the flap and the long, mobile pedicle allows to use for defects of the planum, the sella, the clivus and the craniocervical junction. Complications of this technique can be damage to the frontal branch of the facial nerve, alopecia, and ischemic lesions of the scalp.

3.5 Transfrontal pericranial flap

Pedicled galeopericranial flaps that are based on the supraorbital and supratrochlear arteries are commonly used in conventional operations of the frontal base and can be transposed into the nasal cavity through a bony window of the superior part of the nasion. Although they are usually raised using a bicoronal incision, endoscopic techniques for their elevation have also been described [21]. Since the passage to the frontal sinus will be constricted by the pedicle of the flap, enlargement of the access to the frontal sinus by a Draf III-procedure should always be performed. Due to the location of the flap's pedicle, this flap is especially suitable for defects in the area of the cribriform plate, the planum but it can also be extended up to the sella and the clivus.

3.6 Modification of the (Oliver) pedicled palatal flap

This flap consists of the mucoperiosteum of the hard palate and is vascularized by the major palatine artery that extends from the maxillary artery and travels through the greater palatine foramen. Incisions can be placed bilaterally close to the alveolar ridge and to the posterior aspect of the hard palate. When the mucoperiosteum is pushed off, one of the two neurovascular bundles should be preserved. To allow for the passage of the flap, the foramen has to enlarged using a drill [101]. The posterior wall of the maxillary sinus is then removed endonasally and the palatine artery has to be identified in the pterygopalatine fossa. By elevating the mucosa of the nasal floor the bony canal is exposed and the flap can be transposed into the nasal cavity. This flap has a long pedicle and a large surface (12 to 18.5 cm^2 [101]) and is therefore suited for large defects in the area of the planum, the sella, and the clivus. Especially in cases where Hadad-flaps can't be used, this flap is well suited. Nonetheless, it should be mentioned that the risks of infections with oral pathogens and the development of oronasal fistulas are potential complications of this technique.

4. Classification of endonasal approaches

The systematic classification of endoscopic endonasal approaches to the skull base is mainly owed to Kassam's group, who developed specific modules for training and categorization and is largely accepted by the scientific community [12], [13], [17], [102]. The modules are categorized by means of anatomic corridors with the sphenoid sinus as the central point where the sagittal and coronal planes cross each other.

Sagittal plane

- Transfrontal
- Transcribriform
- Transtuberculum/Transplanum
- Transsellar
- Transclival
  - Superior third
  - Transsellar (intradural)
  - Subsellar (extradural)
  - Middle third
  - Panclival
- Transodontoid and foramen magnum/craniovertebral approach

Coronal plane

- Anterior coronal plane
  - Supraorbital
  - Transorbital
- Middle coronal plane
  - Medial petrous apex
  - Petroclival approaches
  - Inferior cavernous sinus/Quadrangular space
  - Superior cavernous sinus
  - Infratemporal approach
- Posterior coronal plane
  - Infrapetrous
  - Transcondylar
  - Transhypoglossal
  - Parapharyngeal space
  - Medial (jugular foramen)
  - Lateral

4.1 Transsellar approach

The transsellar approach is especially relevant for pituitary surgery and Rathke's cleft cysts. It allows access to medial aspects of the cavernous sinus for pituitary adenomas extending laterally behind the cavernous part of the carotid artery [12].

Procedure

Access to the sphenoid sinuses are enlarged up to the lateral recess of the sphenoid, and the junction between planum, tuberculum, and the optocarotid recess (OCR) are exposed. Optionally, posterior ethmoid cells can be removed to visualize the medial orbital walls. To optimize the trajectory in direction of the supra- and retrosellar area, the sinus floor is drilled down to lowest part of the sphenoid sinus – this can even be extended to the level of the clivus. Septations of the sphenoid sinus should be removed using a drill to achieve sufficient room for the maneuverability of the instruments. This should always be done carefully because these septations can be attached directly to the vertical portion of the carotid canal.

Removal of the mucosa above the sella is the next step. Its complete removal is only advised if it precludes the identification of anatomical landmarks. These are the medial extension of the sella, the bony ridge covering the superior intercavernous sinus, the clival recess, the bony canal of the carotid lateral to the sella, and further cranially the optic canal and the medial and lateral OCR. Now, the bone of the sella is resected above the medial part of the cavernous sinus and this resection is extended cranially and caudally until the superior and inferior intercavernous sinuses are exposed. The medial OCR should only be exposed if the tumor extends to the suprasellar and lateral optocarotid cistern.

Intrasellar dissection

After the dura is open by a cross-shaped incision its inferior portion is translocated in a caudal direction. The caudal part should remain in place to avoid caudal displacement of the suprasellar tumor that would obstruct the vision. The (internal) debulking of the tumor is performed with two suctions to minimize trauma of the normal parts of the gland, the stalk, and the cavernous sinus and its contents. After resection of the posterolateral portion of the tumor, the superior part of the dura is opened to direct the resection superiorly and laterally. Special care is taken for the region posterior to the carotid genu in the cavernous sinus, the medial OCR, and the anterior part of the dura at the level of the superior intercavernous sinus to avoid remaining tumor portions. Residual parts of the gland are frequently located at the undersurface of the diaphragm. If the diaphragm doesn't lower concentrically, the suspicion should be raised that there are suprasellar tumor remnants. If this is the case, the bony surface of the medial OCR has to be removed to enable identification of the carotid artery and the optic nerves. If the tumor extends into the cavernous sinus its medial wall can be investigated from the sella because the carotid siphon is usually replaced anteriorly. This leaves enough room between the posterior clinoid and the siphon to reach the cavernous sinus where the tumor can be followed.

4.2 Extended endonasal approaches – sagittal plane

The sagittal plane extends from the frontal sinus to the second vertebra and enables approach through the christa galli, planum, tuberculum and dorsum sellae and clivus.

4.2.1 Transtuberculum/Transplanum approach

This approach is well suited for pituitary adenomas with suprasellar extension, meningiomas, and selected craniopharyngiomas where a combined transsellar/transplanum approach including the resection of the tuberculum is necessary and permits the complete removal of the neoplasms with direct vision in one step [12].

Procedure

The bony exposure of the transsellar approach is supplemented in an anterior direction by performing complete posterior ethmoidectomies. It is important to assure that the bony septae of the ethmoid are completely removed up to the ethmoid roof and the cribriform plate. Damage to the olfactory epithelium can be avoided by respecting the anterior ethmoidal artery as the anterior limit of the exposition and leaving the superior part of the nasal septum at the skull base. The planum is now drilled in an anterior-posterior direction and opened at the rostral aspect of the sella. The bone covering the intercavernous sinus is resected allowing its exposition, cauterization, displacement, or division. Thereby, a direct approach to suprasellar parts of the tumor up to the prechiasmatic cistern is opened. If the tumor extends intradurally in the area of the OCR its bony strut and the medial clinoids have to be removed with the drill to control perforator vessels. The paraclinoid carotid canal of the carotid artery can also be removed in this area. But in this case the small arteries running from the carotid and posterior ethmoidal arteries at the level of the medial OCR have to be identified and cauterized.

Intradural resection

The extracapsular resection of extracranial neoplasms can then be performed through the parachiasmatic cistern. In this case, the identification of the paraclinoid course of the carotid artery is crucial because it travels intradurally at the level of the medial OCR. To this end its bony canal has to be resected in this segment. If the artery is then followed cranially, the optic nerve is encountered.

An important prerequisite for the extracapsular dissection of the tumor is sufficient thinning of the capsule. This facilitates the sharp dissection of the arachnoidal fibers. Special care should be taken to control vessels on the superior aspects of the tumor. The same is true for the pituitary stalk that shouldn't be injured when coagulations in the region of the skull base between tuberculum and sella are carried out. Furthermore, the infrachiasmatic perforating vessels have to be preserved when the extracapsular dissection is performed.

4.2.2 Transcribriform

The transcribriform approach is predominantly used for the closure of skull base defects with CSF leaks, encephaloceles, meningoceles, and for the removal of benign neoplasms like meningiomas of the olfactory groove as well as for the resection of malignant tumors of the nose and paranasal sinuses [12].

Procedure

This module can be carried out uni- or bilaterally. Its anterior margins are the christa galli and the frontal sinuses and it can be extended to the caudal border of the planum dorsally. Laterally, the medial wall of the orbit or the ethmoidal roof are its limits. Complete ethmoidectomy and removal of the superior parts of the nasal septum at the skull base are prerequisites. If necessary, the lamina papyracea can also be sacrificed but the periorbital fascia should remain intact. The frontal sinus has to be exposed and the extension of its opening can be adapted to the individual situation. According to Draf's classification [103] this could be the removal of the frontal sinus floor lateral to middle turbinate (Draf IIa), resection of the frontal sinus floor lateral to the nasal septum (Draf IIb), or bilateral removal of the sinus floor and the interfrontal septum (Draf III). The anterior and posterior ethmoidal arteries should be identified and coagulated to contribute to the devascularization of the tumor. After coagulation of the olfactory filaments and branches of the ethmoidal arteries, the cribriform plate is drilled and removed. The christa galli is also removed after thinning. The fact that the sense of smell is necessarily sacrificed in this approach is alleviated by the notion that the underlying conditions that lead to this approach have usually already caused hypo- or anosmia.

Intradural dissection

After exposure and coagulation the dura is opened by incisions on both sides of the falx. To allow the bilateral identification of the edges of the falx, the tumor is removed on both sides independently. Only then, the falx is incised to achieve a single workspace. It should be avoided to open the dura anterior to the tumor because this can induce prolapse of brain parenchyma. Now, debulking of the medial parts of the neoplasm can be carried out. During the extracapsular dissection damage to vessels at the interhemispheric fissure such as A2 (A. cerebri anterior) and frontopolar arteries has to be avoided.

4.2.3 Transclival

In a vertical direction the clivus can be divided in three regions: Its upper third includes the dorsum sellae, and the posterior clinoids and is caudally confined by Dorello's canal (through which the abducent nerve enters the cavernous sinus). The middle third is located caudally and ends at the level of the jugular foramen. Its lower third extends to the level of the foramen magnum.
Transclival approaches are indicated for operations of meningiomas, chordomas, and chondrosarcomas, that are the most frequent tumors of the clivus.

Cranial third of the clivus

The dorsum sellae medially and the posterior clinoids laterally constitute the anterior border of the cranial part of the clivus. These bony structures can be removed intradurally through an infrasellar approach by cranial transposition of the sellar contents. To perform a transsellar intradural approach a transtuberculum/transplanum exposition (see above) has to be carried out. After removal of the sellar bone and identification of the intercavernous sinus, the transition to the clivus can be exposed. The dura and the diaphragm are incised and the pituitary capsule and the stalk have to be respected. After incision of ligaments connecting the pituitary laterally, caudal transposition of the gland is enabled [104]. The posterior clinoids can then be drilled and removed carefully avoiding damage to the carotid artery and the abducent nerve that is found laterally and dorsally thus making it possible to reach the retrosellar region directly [102].
Especially in lesion that are located medially and extend into a caudal direction, the infrasellar extradural route can be chosen. To this end, the bone of the sella and above the intercavernous sinus as well as medial of the vertical part of the carotid canal is drilled. The content of the sella can then be transposed cranially without opening the dura. This allows the removal of the posterior clinoids and the dorsum sellae.

Middle third of the clivus

The sole removal of the middle third of the clivus is rarely necessary. Therefore its removal is usually carried out as part of a panclival operation.

Panclival procedure

The removal of the caudal parts of the clivus requires that the access to the sphenoid sinus is drilled far caudally as well. Hereto the fascia of the nasopharynx has to be elevated from the caudal sphenoid and the clivus in a caudal direction. When drilling the lateral parts of the clivus special care should be taken to identify the canal of the vidian nerve and its corresponding artery because they are important landmarks for the localization of the anterior genu of the carotid artery [105]. Cranially of this canal the bone can only be removed medially – between the carotid canals.
When the dura is incised in the midline, bleeding from the venous plexus on the back of the clivus has to be controlled by adequate means such as coagulation. A horizontal opening of the dura allows the identification of the Eustachian tubes that enter the skull base in an oblique direction below the horizontal portion of the carotid artery. Further cranially the abducent nerve has to be mentioned that runs through Dorello's canal into the direction of the anterior carotid genu in a medial, cranial and dorsal course. Additional neurovascular structures such as the vertebral arteries, the vertebro-basilar junction, the basilar artery, the pons, and the cranial nerves V to X should be preserved.

4.2.4 Transodontoid and foramen magnum/craniovertebral approach

In select cases it can be useful to approach the odontoid and the foramen magnum endonasally [102], [106],

[107]. The mucosa of the nasopharynx has to be elevated from the clivus to the level of the soft palate and the paraspinal muscles and the prevertebral fascia have to exposed or removed to obtain sufficient access. The preparation should be kept medial of the Eustachian tubes to avoid laceration of the internal carotid artery. The anterior arch of C1 is exposed and drilled away depending on the underlying pathology and taking cranio-cervical stability into consideration [108]. For visualization of the foramen magnum it is sufficient to drill the cranial part of the C1 ring exposing the odontoid. The medial aspects of the occipital condyles are drilled away conserving the joint capsules. The bone of the odontoid can now be removed gradually to expose the dura of the brainstem. This allows visualization of the cervical spinal cord caudally to the level of C1–C2. Processes that are located more caudally can't be reached because of the limited maneuverability of the endoscopes and instruments in this technique.

4.3 Extended endonasal approaches – coronal plane

These approaches are categorized based on the different cranial fossae and thus divided into anterior, medial, and posterior planes.

4.3.1 Anterior coronal plane: supraorbital and transorbital approaches

To perform supraorbital approaches the medial wall of the orbit needs to be removed and the soft tissue of the orbit displaced laterally to expose the orbital roof. In cases where intraconal lesions caudal and medial of the optic nerve need to be reached the transorbital approach is chosen and accessed between the inferior and medial rectus muscles.

4.3.2 Medial coronal plane

These procedures can be categorized based on the relation to the carotid artery. Infrapetrosal techniques give access to the inferior and superior cavernous sinus and the infratemporal fossa [13].

Medial petrous apex

In this case far caudal exposure through the sphenoid sinus is necessary. Therefore, the anterior wall of the sphenoid is drilled to the level of the clivus. The clivus can also be partially removed if necessary. Exposure of the pterygopalatine fossa is attained by performing large medial antrostomy and removal of the posterior wall of the maxillary sinus [109], [110]. The sphenopalatine artery is ligated and the soft tissue of the pterygopalatine fossa is transposed cranially to expose the medial pterygoid plate. This structure and the vidian canal are the essential anatomical landmarks on the way to the petrous apex [105], [111]. The medial pterygoid plate is now drilled into the direction of the foramen lacerum caudal to the vidian nerve to identify the anterior genu of the carotid. Once it is visualized, the lateral and cranial parts of its bone can be safely removed. It might be necessary to transpose the carotid artery laterally to expose the petrous apex. In this case, the bony structures along the paraclival course of the carotid need to removed as well [112]. Additionally, the lateral parts of the clivus at its junction with the petrous apex can be resected.

Petroclival approach

The beginning of this technique is identical to the medial petrous apex approach. After exposition of the anterior genu of the carotid, that is the most important landmark, the bone above the genu is also removed. This is the horizontal petrous and vertical paraclival course of the carotid canal. The vessel can then be transposed laterally. The medial and lateral parts of the clivus are drilled away. The superior limits of this approach are the cavernous sinus and its lateral limit is the middle fossa. The prepontine cistern is accessed when the dura is incised.

Inferior cavernous sinus

This approach is based on the petroclival technique. In the superior part of the pterygopalatine fossa, the maxillary nerve (V2) is followed to the foramen rotundum. The bone between vidian canal and foramen rotundum is drilled in a dorsal direction. This exposes a space that is confined medially by the parasellar part of the carotid artery, laterally by V2 and the dura of the middle fossa, caudally by the horizontal petrosal course of the carotid, and cranially by the abducent nerve. This technique also allows lateral transposition of the carotid artery after removal of its surrounding bone. Access to the inferior cavernous sinus is gained by dural incision between the anterior genu of the carotid and V2.

Superior cavernous sinus

Neoplasms causing cranial nerve deficits are indications for this approach. In addition to the afore mentioned it is important to expose the medial boundary of the carotid artery in the sella to avoid its injury. The dura is opened directly above the cranial-lateral part of the cavernous sinus. Bleeding from the sinus has to be expected at the latest when the tumor is removed.

Infratemporal approach

For neoplasms that reach into the infratemporal fossa this expansion of the coronal approaches can be utilized. It is necessary to resect the medial pterygoid plate, to expose the anterior genu of the carotid and the horizontal portion of petrous segment of the carotid canal, as well as the foramen rotundum. After ligation of the maxillary artery, debulking of the tumor up to the lateral pterygoid plate can be carried out. This structure can then be removed up to the level of middle fossa and the foramen ovale should be exposed. Bleeding from the venous plexus in the pterygopalatine fossa and destruction of bony structures by the tumor has to be anticipated.

4.3.3 Posterior coronal plane

This plane reaches from the foramen magnum to the occipital condyles and the hypoglossal canal and its lateral boundary is the jugular foramen.

Infrapetrosal

Based upon the infratemporal approach, the nerve V3 is exposed in the foramen rotundum after resection of the lateral pterygoid plates [13]. Parts of the Eustachian tube have to be resected and the caudal portion of the petrous apex can be reached by drilling between the horizontal petrous segment of the carotid canal and the tube (medial to V3). The course of the artery can be followed up to the petrous apex by drilling along its canal.
The additional approaches that are mentioned in the classification system (transcondylar, transhypoglossal, parapharyngeal space, medial (jugular foramen) are not described here.

5. Diagnosis

5.1 Clinical

The clinical symptoms of neoplasms of the paranasal sinuses and the skull base are mostly unspecific in their early stages. Unfortunately, this frequently leads to diagnosis of these tumors in progressed stages. Unilateral, recently occurring symptoms that don't respond to medical therapy should lead to referral to an ENT-specialist. Patients with concomitant orbital or neurological symptoms have to be referred immediately (Table 2).

5.2 Imaging

Imaging is essential for the preoperative evaluation and for surgical planning in benign and malignant neoplasms of the paranasal sinuses and the skull base. Computed tomography (CT) and magnetic resonance imaging (MRI) complement each other in the exact allocation of tumors and their local extension including the assessment of bone and neurovascular structures in this region. These techniques are also a prerequisite for intraoperative navigation and postoperative controls. The cooperation with an experienced neuroradiologist is essential for the surgeon.
Substantial goals of the preoperative imaging are the differentiation between tumor and inflammatory conditions, the distinction between benign and malignant neoplasms, and the exact description of the extension [113]. Although MRI is generally best suited to achieve these goals, in most patients with symptoms of a disease of the sinuses or the skull base a CT-scan is generally performed first. Only in fibro-osseous tumors it is possible to visualize and the lesion and its borders completely by CT – in all other cases, a high-resolution MRI with gadolinium enhancement that includes T1- and T2-weighted images in axial, coronal and sagittal planes has to be performed. For the assessment of intracranial spread or perineural growth usually fat-saturated T1-techniques are carried out [114]. In specific situations the following protocols can also be useful: MR-cisternography with thin T2-weighted sequences (CISS, DRIVE) for evaluation of the association of the tumor to cranial nerves [115], high-resolution, isotropic GE-sequences (FIESTA, VIBE) to investigate cranial nerves in their foramina [116], FLAIR (Fluid-Attenuated Inversion Recovery) for the differentiation between cystic tumor content and CSF or mucoceles, as well as MR-angiography to delineate the course of the internal carotid artery in its entirety.

5.2.1 Intraoperative navigation

The availability and use of intraoperative navigation systems has to be seen as an obligatory prerequisite for the execution of endonasal, endoscopic skull base surgery [117], [118]. Of course, it can't substitute detailed anatomical knowledge but it leads to improved orientation and thus safety. Image-guidance systems enable the exact localization of instruments in the operation based on preoperative CT-images. Nowadays, the quality of the depiction of soft tissue structures can be largely improved by performing fusion of CT- and MRI-images [119], [120]. A clinically relevant limitation occurs when the position of soft-tissue structures is changed intraoperatively ("brain-shift"). This can e.g. happen when the carotid artery is transposed medially into the sphenoid sinus after the resection of its bony canal. These problems could be solved by using intraoperative imaging. Potentially, different modalities such as CT [121], MRI, and sonography [122] can be used to achieve this goal.

5.2.2 Postoperative control

Regular postoperative imaging is obligatory not only in malignant tumors of the paranasal sinuses and the skull base but also in select benign neoplasms this is recommended. This is the case for lesions that could be missed in the endoscopic evaluation because of their (deep) location or submucosal growth. Examples are juvenile angiofibroma, pituitary adenoma, epidermoid cysts, craniopharyngioma, and meningioma. In inverted papilloma postoperative imaging is only indicated when recurrence is proven histologically, the access to the relevant sinus is closed, or the patient is symptomatic.
Generally, postoperative controls are performed with MRI. They are carried out to detect recurrence and possible complications such as mucocele formation. A typical rhythm are 4-monthly in the first one to two years and every 6 months afterwards [90], [113]. For tumors that are prone to late recurrences e.g. chondrosarcoma, ad-

Table 2: Clinical symptoms of tumors of the nose and paranasal sinuses depending on the primary localization and the direction of growth (modified after Lund [40])

Localization	Direction of growth	Symptoms
Nasal cavity		nasal blockage, epistaxis, secretion, hyposmia
	caudally into palate	tumor, ulceration, fistula
	dorsally into nasopharynx	middle ear effusion, deafness
	anterior-superiorly into nasal bone	glabellar mass
	externally into skin	tumor, ulceration
	cranially into anterior cranial fossa	minimal, personality change, headache, neurological deficit, CSF-leak, rarely meningitis
Maxillary sinus	medially into nasal cavity	nasal blockage, epistaxis, secretion, hyposmia
	anteriorly into cheek	tumor, ulceration, paresthesia
	posteriorly into pterygopalatine fossa or infratemporal fossa	trismus, pain
	caudally into palate or alveolar ridge	tumor, loosening of teeth, fistula
	cranially into orbit	proptosis, diplopia
Ethmoid sinus	medially into nasal cavity	nasal blockage, epistaxis, secretion, hyposmia
	caudally-lateral into maxilla	mucus retention
	medially into orbit	proptosis, chemosis, diplopia, visual loss, epiphora
	cranially into anterior cranial fossa	minimal, personality change, headache, neurological deficit, CSF-leak, rarely meningitis
Frontal sinus	anteriorly	tumor of the forehead or glabella
	dorsally into anterior cranial fossa	minimal, personality change, headache, neurological deficit, CSF-leak, rarely meningitis
	caudally into nasal cavity	nasal blockage, epistaxis, secretion, hyposmia
	caudally into orbit	proptosis, chemosis, diplopia, visual loss, epiphora
	medially into contralateral frontal sinus	none, as long as the limits of the sinus are not transgressed

enoid cystic carcinoma, and olfactory neuroblastoma the period should be extended over the typical 5 years.

It is crucial for the assessment that the typical radiological characteristics of postoperative healing and scar formation are known to the radiologist. Furthermore, he has to informed about the details of the surgical procedure. These include the degree of resection, information about the method of reconstruction, the histopathological results, and postoperative radiotherapy. Knowledge about the characteristics of the vascularized flaps is relevant for the evaluation of MRI-scans in order to differentiate between abnormal healing and necrosis or displacement of the flap, and tumor recurrence [96]. It can also be challenging to distinguish inflammatory conditions from granulations or tumor recurrence [114].

6. Interdisciplinarity and education

Endonasal endoscopic skull base surgery is a team game. Apart from the undeniable fact that fourhanded surgical techniques can't be performed by a single surgeon due to anatomical realities, there are a number of additional arguments for working in a team.

Especially due to the increasing complexity of the operations in this region it has to be assured that complications can always be handled adequately. This implies that alternative approaches or techniques have to be feasible and available. For example, operations where the integrity of the wall of the internal carotid artery is in danger should not be performed without the availability of a neuroradiologist experienced in carrying out intraluminal procedures of this vessel. The same is true for many other situations. Furthermore, the discussion about the optimal technique for specific cases can only profit from the different perspective of other disciplines. Our advice is

Table 3: Training program for endonasal skull base surgery (modified after Snyderman [17])

Level	Operation	
Level I	Endoscopic sinus surgery	
	Extended endoscopic frontal sinus surgery	
	Sphenopalatine artery ligation	
Level II	Advanced endoscopic sinus surgery	
	Reconstruction of skull base defects	
	Lateral recess of sphenoid sinus	
	Sella/pituitary (intrasellar)	
Level III (Extradural)	Medial orbital decompression	
	Optic nerve decompression	
	Sella/ pituitary (extrasellar)	
	Petrous apex (medial part)	
	Transclival approach (extradural)	
	Transodontoid approach (extradural)	
Level IV (Intradural)	A. Intracranial extension	Transplanum approach
		Transcribriform approach
		Neoplasm rostral of pituitary stalk
	B. No intracranial extension (direct contact to vessels)	Transplanum approach
		Transcribriform approach
		Neoplasm of pituitary stalk
		Neoplasm dorsal of pituitary stalk
		Transclival approach
		Foramen magnum approach
	C. Dissection of internal carotid artery (ICA)	
Level V	A. Middle coronal plane (paramedian)	Suprapetrous approach to ICA
		Infrapetrous approach to ICA
		Transpterygoid approach
		Infratemporal approach
	B. Posterior coronal plane (paramedian)	
	C. Vascular surgery	

therefore that (endonasal) skull base surgery should only be performed in centers where at least the cooperation of ENT-surgeons, neurosurgeons, and neuroradiologists is ensured. The collaboration of oral and maxillofacial surgeons, ophthalmologists, and (neuro-) pathologists is also useful.
The endoscopically experienced otorhinolaryngologist has a central role here because there is no other discipline active in the region of the head and neck where surgical procedures with rigid endoscopes are so deeply rooted in the training and daily routine. On the other hand it is necessary for ENT-surgeons active in skull base surgery to obtain anatomical, surgical, and diagnostic knowledge that is traditionally more related to neurosurgery.
To obtain the obligatory expertise, Snyderman suggested a stepwise training program for endonasal endoscopic skull base surgery (Table 3). One level should be safely controlled before moving to the next one because the associated risks increase with each level due to also increased anatomical complexity, and the necessary technical skills. Specific learning curves exist for each of the modules [14], [123]. The steepest probably for the middle coronal plane [17].
The relevance of studying the anatomical relations of the skull base – ideally as well theoretically as practically (anatomical dissections) can't be stressed enough in this context.

References

1. Laufer I, Anand VK, Schwartz TH. Endoscopic, endonasal extended transsphenoidal, transplanum transtuberculum approach for resection of suprasellar lesions. J Neurosurg. 2007; 106: 400-6. DOI: 10.3171/jns.2007.106.3.400
2. Carrabba G, Dehdashti AR, Gentili F. Surgery for clival lesions: open resection versus the expanded endoscopic endonasal approach. Neurosurgical focus. 2008; 25: E7. DOI: 10.3171/FOC.2008.25.12.E7
3. de Divitiis E, Cavallo LM, Cappabianca P, Esposito F. Extended endoscopic endonasal transsphenoidal approach for the removal of suprasellar tumors: Part 2. Neurosurgery. 2007; 60: 46-58. DOI: 10.1227/01.NEU.0000249211.89096.25

4. de Divitiis E, Cappabianca P, Cavallo LM, Esposito F, de Divitiis O, Messina A. Extended endoscopic transsphenoidal approach for extrasellar craniopharyngiomas. Neurosurgery. 2007; 61: 219-27. DOI: 10.1227/01.neu.0000303220.55393.73

5. de Divitiis E, Esposito F, Cappabianca P, Cavallo LM, de Divitiis O, Esposito I. Endoscopic transnasal resection of anterior cranial fossa meningiomas. Neurosurgical focus. 2008; 25: E8. DOI: 10.3171/FOC.2008.25.12.E8

6. Dehdashti AR, Ganna A, Witterick I, Gentili F. Expanded endoscopic endonasal approach for anterior cranial base and suprasellar lesions: indications and limitations. Neurosurgery. 2009; 64: 677-87. DOI: 10.1227/01.NEU.0000339121.20101.85

7. Fatemi N, Dusick JR, de Paiva Neto MA, Malkasian D, Kelly DF. Endonasal versus supraorbital keyhole removal of craniopharyngiomas and tuberculum sellae meningiomas. Neurosurgery. 2009; 64: 269-84. DOI: 10.1227/01.NEU.0000327857.22221.53

8. Frank G, Pasquini E, Doglietto F, Mazzatenta D, Sciarretta V, Farneti G, Calbucci F. The endoscopic extended transsphenoidal approach for craniopharyngiomas. Neurosurgery. 2006; 59: ONS75-83. DOI: 10.1227/01.NEU.0000219897.98238.A3

9. Fraser JF, Nyquist GG, Moore N, Anand VK, Schwartz TH. Endoscopic endonasal transclival resection of chordomas: operative technique, clinical outcome, and review of the literature. J Neurosurg. 2010; 112: 1061-9. DOI: 10.3171/2009.7.JNS081504

10. Gardner PA, Kassam AB, Snyderman CH, Carrau RL, Mintz AH, Grahovac S, Stefko S. Outcomes following endoscopic, expanded endonasal resection of suprasellar craniopharyngiomas: a case series. J Neurosurg. 2008; 109: 6-16. DOI: 10.3171/JNS/2008/109/7/0006

11. Zada G, Kelly DF, Cohan P, Wang C, Swerdloff R. Endonasal transsphenoidal approach for pituitary adenomas and other sellar lesions: an assessment of efficacy, safety, and patient impressions. J Neurosurg. 2003; 98: 350-8. DOI: 10.3171/jns.2003.98.2.0350

12. Kassam AB, Snyderman CH, Mintz AH, Gardner P, Carrau RL. Expanded endonasal approach: the rostrocaudal axis. Part I. Crista galli to the sella turcica. Neurosurgical focus. 2005; 19: E3. DOI: 10.3171/foc.2005.19.1.4

13. Kassam AB, Gardner P, Snyderman CH, Mintz AH, Carrau RL. Expanded endonasal approach: fully endoscopic, completely transnasal approach to the middle third of the clivus, petrous bone, middle cranial fossa, and infratemporal fossa. Neurosurgical focus. 2005; 19: E6. DOI: 10.3171/foc.2005.19.1.7

14. O'Malley BW Jr, Grady MS, Gabel BC, Cohen MA, Heuer GG, Pisapia J, Bohman LE, Leibowitz JM. Comparison of endoscopic and microscopic removal of pituitary adenomas: single-surgeon experience and the learning curve. Neurosurg Focus. 2008; 25: E10. DOI: 10.3171/FOC.2008.25.12.E10

15. Gardner PA, Kassam AB, Thomas A, Snyderman CH, Carrau RL, Mintz AH, Prevedello DM. Endoscopic endonasal resection of anterior cranial base meningiomas. Neurosurgery. 2008; 63: 36-52. DOI: 10.1227/01.NEU.0000335069.30319.1E

16. Tabaee A, Anand VK, Barron Y, Hiltzik DH, Brown SM, Kacker A, Mazumdar M, Schwartz TH. Endoscopic pituitary surgery: a systematic review and meta-analysis. J Neurosurg. 2009; 111: 545-54. DOI: 10.3171/2007.12.17635

17. Snyderman CH, Carrau RL, Kassam AB, Zanation A, Prevedello D, Gardner P, Mintz A. Endoscopic skull base surgery: principles of endonasal oncological surgery. J Surg Oncol. 2008; 97: 658-64. DOI: 10.1002/jso.21020

18. Kassam AB, Snyderman CH, Carrau RL, Gardner P, Mintz AH. Endoneurosurgical hemostasis techniques: lessons learned from 400 cases. Neurosurgical focus. 2005; 19: E7. DOI: 10.3171/foc.2005.19.1.8

19. Kassam AB, Carrau RL, Snyderman CH, Gardner P, Mintz AH. Evolution of reconstructive techniques following endoscopic expanded endonasal approaches. Neurosurgical focus. 2005; 19: E8. DOI: 10.3171/foc.2005.19.1.9

20. Kassam AB, Thomas A, Carrau RL, Snyderman CH, Vescan A, Prevedello D, Mintz A, Gardner P. Endoscopic reconstruction of the cranial base using a pedicled nasoseptal flap. Neurosurgery. 2008; 63: ONS44-52. DOI: 10.1227/01.NEU.0000297074.13423.F5

21. Zanation AM, Snyderman CH, Carrau RL, Kassam AB, Gardner PA, Prevedello DM. Minimally invasive endoscopic pericranial flap: a new method for endonasal skull base reconstruction. Laryngoscope. 2009; 119: 13-8. DOI: 10.1002/lary.20022

22. Miller CA. A case of hydrocephalus chronicus, with some unusual symptoms and appearance on dissection. Transactions of the Medico-Chirurgical Society of Edinburgh. 1826; 2: 243-8.

23. Thomson SC. The cerebro-spinal fluid; its spontaneous escape from the nose : with observations on its composition and function in the human subject. London: Cassell & Company; 1899.

24. Dandy W. Pneumocephalus (intracranial pneumatocele or aerocele). Archives of Surgery. 1926; 12: 949-82. DOI: 10.1001/archsurg.1926.01130050003001

25. Dohlman G. Spontaneous cerebrospinal rhinorrhoea: case operated by rhinologic methods. Acta Oto-Laryngologica Supplementum. 1948; 67: 20-3. DOI: 10.3109/00016484809129635

26. Hirsch O. Successful closure of cerebrospinal fluid rhinorrhea by endonasal surgery. Archives of Otolaryngology. 1952; 56: 1-12. DOI: 10.1001/archotol.1952.00710020018001

27. Messerklinger W. Nasenendoskopie: Nachweis, Lokalisation und Differentialdiagnose der nasalen Liquorrhoe [Nasal endoscopy: demonstration, localization and differential diagnosis of nasal liquorrhea]. HNO. 1972; 20: 268-70.

28. Messerklinger W. Endoscopy of the nose. Baltimore: Urban & Schwarzenberg; 1978.

29. Aarabi B, Leibrock LG. Neurosurgical approaches to cerebrospinal fluid rhinorrhea. Ear Nose Throat J. 1992; 71: 300-5.

30. Hughes RG, Jones NS, Robertson IJ. The endoscopic treatment of cerebrospinal fluid rhinorrhoea: the Nottingham experience. J Laryngol Otol. 1997; 111: 125-8. DOI: 10.1017/S0022215100136643

31. Carmel P, Komisar A. Cerebrospinal fluid rhinorrhea. In: Blitzer A, Lawson W, Friedman W, Hrsg. Surgery of the paranasal sinuses. Philadelphia: W.B.Saunders; 1991. S. 377-88.

32. Dodson EE, Gross CW, Swerdloff JL, Gustafson LM. Transnasal endoscopic repair of cerebrospinal fluid rhinorrhea and skull base defects: a review of twenty-nine cases. Otolaryngol Head Neck Surg. 1994; 111: 600-5.

33. Hisamatsu K, Ganbo T. Spontaneous cerebrospinal fluid rhinorrhea through the cribriform plate fistula cured by endonasal surgery: transseptal submucoperiosteal obliteration of the olfactory cleft. Otolaryngol Head Neck Surg. 1995; 113: 822-5. DOI: 10.1016/S0194-5998(95)70032-3

34. Anand VK, Murali RK, Glasgold MJ. Surgical decisions in the management of cerebrospinal fluid rhinorrhoea. Rhinology. 1995; 33: 212-8.

35. Briggs RJS, Wormald PJ. Endoscopic transnasal intradural repair of anterior skull base cerebrospinal fluid fistulae. J Clin Neurosci. 2004; 11: 597-9. DOI: 10.1016/j.jocn.2003.09.011

36. Hosemann W, Nitsche N, Rettinger G, Wigand ME. Die endonasale, endoskopisch kontrollierte Versorgung von Duradefekten der Rhinobasis [Endonasal, endoscopically controlled repair of dura defects of the anterior skull base]. Laryngorhinootologie. 1991; 70: 115-9. DOI: 10.1055/s-2007-998001

37. Lanza DC, O'Brien DA, Kennedy DW. Endoscopic repair of cerebrospinal fluid fistulae and encephaloceles. Laryngoscope. 1996; 106: 1119-25. DOI: 10.1097/00005537-199609000-00015

38. Marks SC. Middle turbinate graft for repair of cerebral spinal fluid leaks. Am J Rhinol. 1998; 12: 417-9. DOI: 10.2500/105065898780707900

39. Stammberger H, Greistorfer K, Wolf G, Luxenberger W. Operativer Verschluss von Liquorfisteln der vorderen Schädelbasis unter intrathekaler Natriumfluoreszeinanwendung [Closure of CSF Leaks of the Anterior Skull Base Using Intrathekal Sodium Fluorescein]. Laryngo Rhino Otol. 1997; 76: 595-607. DOI: 10.1055/s-2007-997487

40. Lund VJ, Stammberger H, Nicolai P, Castelnuovo P. European Position Paper on Endoscopic Management of Tumours of the Nose, Paranasal Sinuses and Skull Base. Rhinology. 2010; Suppl 22: 1-146.

41. Schnabel C, Di Martino E, Gilsbach JM, Riediger D, Gressner AM, Kunz D. Comparison of beta2-transferrin and beta-trace protein for detection of cerebrospinal fluid in nasal and ear fluids. Clin Chem. 2004; 50: 661-3. DOI: 10.1373/clinchem.2003.024158

42. Sampaio MH, De Barros-Mazon S, Sakano E, Chone CT. Predictability of quantification of beta-trace protein for diagnosis of cerebrospinal fluid leak: Cutoff determination in nasal fluids with two control groups. Am J Rhinol Allergy. 2009; 23: 585-90. DOI: 10.2500/ajra.2009.23.3409

43. Roelandse FW, van der Zwart N, Didden JH, van Loon J, Souverijn JH. Detection of CSF leakage by isoelectric focusing on polyacrylamide gel, direct immunofixation of transferrins, and silver staining. Clin Chem. 1998; 44: 351-3.

44. Marshall AH, Jones NS. Cerebrospinal fluid rhinorrhea. In: Scott-Brown's otorhinolaryngology, head and neck surgery. London: Hodder Arnold; 2008. p. 1636-44.

45. Wolf G, Greistorfer K, Stammberger H. Der endoskopische Nachweis von Liquorfisteln mittels der Fluoreszeintechnik – Ein Erfahrungsbericht über 925 Fälle [Endoscopic Identification of CSF Leaks using Intrathecal Fluorescein – A Report on 925 Cases]. Laryngo Rhino Otol. 1997; 76: 588-94. DOI: 10.1055/s-2007-997486

46. Keerl R, Weber RK, Draf W, Radziwill R, Wienke A. Complications of lumbar administration of 5% sodium fluorescein solution for detection of cerebrospinal fluid fistula. Laryngo Rhino Otol. 2004; 82: 833-8.

47. Keerl R, Weber RK, Draf W, Wienke A, Schaefer SD. Use of sodium fluorescein solution for detection of cerebrospinal fluid fistulas: an analysis of 420 administrations and reported complications in Europe and the United States. Laryngoscope. 2004; 114: 266-72. DOI: 10.1097/00005537-200402000-00016

48. Zuckerman J, Stankiewicz JA, Chow JM. Long-term outcomes of endoscopic repair of cerebrospinal fluid leaks and meningoencephaloceles. Am J Rhinol. 2005; 19: 582-7.

49. Sethi DS, Chan C, Pillay PK. Endoscopic management of cerebrospinal fluid fistulae and traumatic cephalocoele. Ann Acad Med Singap. 1996; 25: 724-7.

50. Wormald PJ, McDonogh M. The bath-plug closure of anterior skull base cerebrospinal fluid leaks. Am J Rhinol. 2003; 17: 299-305.

51. Maier W. Biomaterialien in der Schädelbasischirurgie [Biomaterials in Reconstructive Skull Base Surgery]. Laryngo Rhino Otol. 2009; 88: S64-S75. DOI: 10.1055/s-0028-1119507

52. Arndt S, Maier W, Aschendorff A, Klenzner T, Schipper J. Ethisorb/Ethisorb Durapatch bei der transnasalen Duraplastik [Ethisorb/Ethisorb durapatch for the transnasal duraplasty procedure?]. Laryngorhinootologie. 2006; 85: 260-4. DOI: 10.1055/s-2005-921055

53. Seidl RO, Todt I, Ernst A. Rekonstruktion von traumatischen Schädelbasisdefekten mit einem alloplastischen, resorbierbaren Vlies (Ethisorb) [Reconstruction of traumatic skull base defects with alloplastic, resorbable fleece]. HNO. 2000; 48: 753-7. DOI: 10.1007/s001060050654

54. Harvey RJ, Smith JE, Wise SK, Patel SJ, Frankel BM, Schlosser RJ. Intracranial complications before and after endoscopic skull base reconstruction. Am J Rhinol. 2008; 22: 516-21.

55. Cappabianca P, Esposito F, Cavallo LM, Messina A, Solari D, di Somma LGM, de Divitiis E. Use of equine collagen foil as dura mater substitute in endoscopic endonasal transsphenoidal surgery. Surg Neurol. 2006; 65: 144-8. DOI: 10.1016/j.surneu.2005.08.023

56. Casiano RR, Jassir D. Endoscopic cerebrospinal fluid rhinorrhea repair: is a lumbar drain necessary? Otolaryngol Head Neck Surg. 1999; 121: 745-50. DOI: 10.1053/hn.1999.v121.a98754

57. Lopatin AS, Kapitanov DN, Potapov AA. Endonasal endoscopic repair of spontaneous cerebrospinal fluid leaks. Arch Otolaryngol Head Neck Surg. 2003; 129: 859-63. DOI: 10.1001/archotol.129.8.859

58. Lindstrom DR, Toohill RJ, Loehrl TA, Smith TL. Management of cerebrospinal fluid rhinorrhea: the Medical College of Wisconsin experience. Laryngoscope. 2004; 114: 969-74. DOI: 10.1097/00005537-200406000-00003

59. Stammberger H. Functional endoscopic sinus surgery: the Messerklinger technique. Philadelphia: BC Decker; 1991.

60. Forer B, Sethi DS. Endoscopic repair of cerebrospinal fluid leaks in the lateral sphenoid sinus recess. J Neurosurg. 2010; 112: 444-8. DOI: 10.3171/2009.7.JNS09306

61. Castelnuovo P, Mauri S, Locatelli D, Emanuelli E, Delù G, Giulio GD. Endoscopic repair of cerebrospinal fluid rhinorrhea: learning from our failures. Am J Rhinol. 2001; 15: 333-42.

62. Bolger WE. Endoscopic transpterygoid approach to the lateral sphenoid recess: surgical approach and clinical experience. Otolaryngol Head Neck Surg. 2005; 133: 20-6. DOI: 10.1016/j.otohns.2005.03.063

63. Lai SY, Kennedy DW, Bolger WE. Sphenoid encephaloceles: disease management and identification of lesions within the lateral recess of the sphenoid sinus. Laryngoscope. 2002; 112: 1800-5. DOI: 10.1097/00005537-200210000-00018

64. Pasquini E, Sciarretta V, Farneti G, Mazzatenta D, Modugno GC, Frank G. Endoscopic treatment of encephaloceles of the lateral wall of the sphenoid sinus. Minimally invasive neurosurgery : MIN. 2004; 47: 209-13.

65. Schick B, Kahle G, Weber R, Draf W. Erfahrungen in der Diagnostik okkulter traumatischer Duraläsionen der vorderen Schädelbasis [Experiences in diagnosis of occult traumatic dural lesions of the anterior cranial base]. Laryngorhinootologie. 1998; 77: 144-9. DOI: 10.1055/s-2007-996949

66. Tomazic PV, Stammberger H. Spontaneous CSF-leaks and meningoencephaloceles in sphenoid sinus by persisting Sternberg's canal. Rhinology. 2009; 47: 369-74.

67. Muscatello L, Lenzi R, Dallan I, Seccia V, Marchetti M, Sellari-Franceschini S. Endoscopic transnasal management of cerebrospinal fluid leaks of the sphenoid sinus. J Craniomaxillofac Surg. 2010; 38: 396-402. DOI: 10.1016/j.jcms.2009.10.013

68. Gendeh BS, Mazita A, Selladurai BM, Jegan T, Jeevanan J, Misiran K. Endonasal endoscopic repair of anterior skull-base fistulas: the Kuala Lumpur experience. J Laryngol Otol. 2005; 119: 866-74. DOI: 10.1258/002221505774783421

69. Nyquist GG, Anand VK, Mehra S, Kacker A, Schwartz TH. Endoscopic endonasal repair of anterior skull base non-traumatic cerebrospinal fluid leaks, meningoceles, and encephaloceles. J Neurosurg. 2009.

70. Lund VJ. Endoscopic management of cerebrospinal fluid leaks. Am J Rhinol. 2002; 16: 17-23.

71. Zweig JL, Carrau RL, Celin SE, Schaitkin BM, Pollice PA, Snyderman CH, Kassam A, Hegazy H. Endoscopic repair of cerebrospinal fluid leaks to the sinonasal tract: predictors of success. Otolaryngol Head Neck Surg. 2000; 123: 195-201. DOI: 10.1067/mhn.2000.107452

72. Orlando R, Cappabianca P, Tosone G, Esposito F, Piazza M, de Divitiis E. Retrospective analysis of a new antibiotic chemoprophylaxis regimen in 170 patients undergoing endoscopic endonasal transsphenoidal surgery. Surg Neurol. 2007; 68: 145-8. DOI: 10.1016/j.surneu.2006.10.063

73. Gil Z, Patel SG, Bilsky M, Shah JP, Kraus DH. Complications after craniofacial resection for malignant tumors: are complication trends changing? Otolaryngol Head Neck Surg. 2009; 140: 218-23. DOI: 10.1016/j.otohns.2008.10.042

74. Kraus DH, Gonen M, Mener D, Brown AE, Bilsky MH, Shah JP. A standardized regimen of antibiotics prevents infectious complications in skull base surgery. Laryngoscope. 2005; 115: 1347-57. DOI: 10.1097/01.mlg.0000172201.61487.69

75. Solero CL, DiMeco F, Sampath P, Mattavelli F, Pizzi N, Salvatori P, Cantù G. Combined anterior craniofacial resection for tumors involving the cribriform plate: early postoperative complications and technical considerations. Neurosurgery. 2000; 47: 1296-304. DOI: 10.1097/00006123-200012000-00007

76. van Aken MO, de Marie S, van der Lely AJ, Singh R, van den Berge JH, Poublon RM, Fokkens WJ, Lamberts SW, de Herder WW. Risk factors for meningitis after transsphenoidal surgery. Clin Infect Dis. 1997; 25: 852-6. DOI: 10.1086/515533

77. Carrau RL, Snyderman C, Janecka IP, Sekhar L, Sen C, D'Amico F. Antibiotic prophylaxis in cranial base surgery. Head Neck. 1991; 13: 311-7. DOI: 10.1002/hed.2880130407

78. Weber RK. Nasentamponaden und Stents [Nasal Packing and Stenting]. Laryngo Rhino Otol. 2009; 88: S139-S155. DOI: 10.1055/s-0028-1119504

79. Harvey RJ, Nogueira JF, Schlosser RJ, Patel SJ, Vellutini E, Stamm AC. Closure of large skull base defects after endoscopic transnasal craniotomy, Clinical article. J Neurosurg. 2009; 111: 371-9. DOI: 10.3171/2008.8.JNS08236

80. Horiguchi K, Murai H, Hasegawa Y, Hanazawa T, Yamakami I, Saeki N. Endoscopic endonasal skull base reconstruction using a nasal septal flap: surgical results and comparison with previous reconstructions. Neurosurg Rev. 2010; 33: 235-41. DOI: 10.1007/s10143-010-0247-8

81. Alameda YA, Busquets JM, Portela JC. Anterior skull base cerebrospinal fluid fistulas in Puerto Rico: treatment and outcome. Bol Asoc Med P R. 2009; 101: 29-33.

82. Locatelli D, Rampa F, Acchiardi I, Bignami M, De Bernardi F, Castelnuovo P. Endoscopic endonasal approaches for repair of cerebrospinal fluid leaks: nine-year experience. Neurosurgery. 2006; 58: ONS-246-56. DOI: 10.1227/01.NEU.0000193924.65297.3F

83. Hegazy HM, Carrau RL, Snyderman CH, Kassam A, Zweig J. Transnasal endoscopic repair of cerebrospinal fluid rhinorrhea: a meta-analysis. Laryngoscope. 2000; 110: 1166-72. DOI: 10.1097/00005537-200007000-00019

84. Schick B, Ibing R, Brors D, Draf W. Long-term study of endonasal duraplasty and review of the literature. Ann Otol Rhinol Laryngol. 2001; 110: 142-7.

85. Hadad G, Bassagasteguy L, Carrau RL, Mataza JC, Kassam AB, Snyderman CH, Mintz AH. A novel reconstructive technique after endoscopic expanded endonasal approaches: vascular pedicle nasoseptal flap. Laryngoscope. 2006; 116: 1882-6. DOI: 10.1097/01.mlg.0000234933.37779.e4

86. Zanation AM, Carrau RL, Snyderman CH, Germanwala AV, Gardner PA, Prevedello DM, Kassam AB. Nasoseptal flap reconstruction of high flow intraoperative cerebral spinal fluid leaks during endoscopic skull base surgery. Am J Rhinol Allergy. 2009; 23: 518-21.

87. El-Banhawy OA, Halaka AN, Ayad H, El-Altuwaijri M, El-Sharnoby MM. Long-term endonasal endoscopic review of successful duraplasty after endonasal endoscopic skull base surgery. Am J Rhinol. 2008; 22: 175-81. DOI: 10.2500/ajr.2008.22.3157

88. Moyer JS, Chepeha DB, Teknos TN. Contemporary skull base reconstruction. Curr Opin Otolaryngol Head Neck Surg. 2004; 12: 294-9. DOI: 10.1097/01.moo.0000131445.27574.be

89. Neovius E, Engstrand T. Craniofacial reconstruction with bone and biomaterials: review over the last 11 years. J Plast Reconstr Aesthet Surg. 2010; 63: 1615-23. DOI: 10.1016/j.bjps.2009.06.003

90. Nicolai P, Battaglia P, Bignami M, Bolzoni Villaret A, Del G, Khrais T, Lombardi D, Castelnuovo P. Endoscopic surgery for malignant tumors of the sinonasal tract and adjacent skull base: A 10-year experience. Am J Rhinol. 2008; 22: 308-316. DOI: 10.2500/ajr.2008.22.3170

91. El-Sayed IH, Roediger FC, Goldberg AN, Parsa AT, McDermott MW. Endoscopic reconstruction of skull base defects with the nasal septal flap. Skull Base. 2008; 18: 385-94. DOI: 10.1055/s-0028-1096202

92. Cavallo LM, Messina A, Esposito F, de Divitiis O, Dal Fabbro M, de Divitiis E, Cappabianca P. Skull base reconstruction in the extended endoscopic transsphenoidal approach for suprasellar lesions. J Neurosurg. 2007; 107: 713-20. DOI: 10.3171/JNS-07/10/0713

93. Esposito F, Cappabianca P, Fusco M, Cavallo LM, Bani GG, Biroli F, Sparano A, de Divitiis O, Signorelli A. Collagen-only biomatrix as a novel dural substitute. Examination of the efficacy, safety and outcome: clinical experience on a series of 208 patients. Clin Neurol Neurosurg. 2008; 110: 343-51. DOI: 10.1016/j.clineuro.2007.12.016

94. Pinheiro-Neto CD, Prevedello DM, Carrau RL, Snyderman CH, Mintz A, Gardner P, Kassam A. Improving the design of the pedicled nasoseptal flap for skull base reconstruction: a radioanatomic study. Laryngoscope. 2007; 117: 1560-9. DOI: 10.1097/MLG.0b013e31806db514

95. Nyquist GG, Anand VK, Singh A, Schwartz TH. Janus flap: bilateral nasoseptal flaps for anterior skull base reconstruction. Otolaryngol Head Neck Surg. 2010; 142: 327-31. DOI: 10.1016/j.otohns.2009.12.020

96. Kang MD, Escott E, Thomas AJ, Carrau RL, Snyderman CH, Kassam AB, Rothfus W. The MR imaging appearance of the vascular pedicle nasoseptal flap. AJNR Am J Neuroradiol. 2009; 30: 781-6. DOI: 10.3174/ajnr.A1453

97. Zanation AM, Carrau RL, Snyderman CH, Mckinney KA, Wheless SA, Bhatki AM, Gardner PA, Prevedello DM, Kassam AB. Nasoseptal flap takedown and reuse in revision endoscopic skull base reconstruction. Laryngoscope. 2011: ePub ahead of print.

98. Fortes FSG, Carrau RL, Snyderman CH, Prevedello DM, Vescan AD, Mintz AH, Gardner P, Kassam AB. The posterior pedicle inferior turbinate flap: a new vascularized flap for skull base reconstruction. Laryngoscope. 2007; 117: 1329-32. DOI: 10.1097/mlg.0b013e318062111f

99. Prevedello DM, Barges-Coll J, Fernandez-Miranda JC, Morera V, Jacobson D, Madhok R, dos Santos MCJ, Zanation A, Snyderman CH, Gardner P, Kassam AB, Carrau R. Middle turbinate flap for skull base reconstruction: cadaveric feasibility study. Laryngoscope. 2009; 119: 2094-8. DOI: 10.1002/lary.20226

100. Fortes FSG, Carrau RL, Snyderman CH, Kassam AB, Prevedello DM, Vescan AD, Mintz AH, Gardner P. Transpterygoid transposition of a temporoparietal fascia flap: a new method for skull base reconstruction after endoscopic expanded endonasal approaches. Laryngoscope. 2007; 117: 970-6. DOI: 10.1097/MLG.0b013e3180471482

101. Oliver CL, Hackman TG, Carrau RL, Snyderman CH, Kassam AB, Prevedello DM, Gardner P. Palatal flap modifications allow pedicled reconstruction of the skull base. Laryngoscope. 2008; 118: 2102-6. DOI: 10.1097/MLG.0b013e318184e719

102. Kassam AB, Snyderman CH, Mintz AH, Gardner P, Carrau RL. Expanded endonasal approach: the rostrocaudal axis. Part II. Posterior clinoids to the foramen magnum. Neurosurgical focus. 2005; 19: E4.

103. Draf W, Weber R, Keerl R, Constantinidis J. Current aspects of frontal sinus surgery. I: Endonasal frontal sinus drainage in inflammatory diseases of the paranasal sinuses. HNO. 1995; 43: 352-7.

104. Kassam AB, Prevedello DM, Thomas A, Gardner P, Mintz A, Snyderman C, Carrau R. Endoscopic endonasal pituitary transposition for a transdorsum sellae approach to the interpeduncular cistern. Neurosurgery. 2008; 62: 57-72. DOI: 10.1227/01.neu.0000317374.30443.23

105. Osawa S, Rhoton AL, Seker A, Shimizu S, Fujii K, Kassam AB. Microsurgical and endoscopic anatomy of the vidian canal. Neurosurgery. 2009; 64: 385-411. DOI: 10.1227/01.NEU.0000338945.54863.D9

106. Messina A, Bruno MC, Decq P, Coste A, Cavallo LM, de Divittis E, Cappabianca P, Tschabitscher M. Pure endoscopic endonasal odontoidectomy: anatomical study. Neurosurg Rev. 2007; 30: 189-94. DOI: 10.1007/s10143-007-0084-6

107. Kassam AB, Snyderman C, Gardner P, Carrau R, Spiro R. The expanded endonasal approach: a fully endoscopic transnasal approach and resection of the odontoid process: technical case report. Neurosurgery. 2005; 57: E213. DOI: 10.1227/01.NEU.0000163687.64774.E4

108. Wu JC, Huang WC, Cheng H, Liang ML, Ho CY, Wong TT, Shih YH, Yen YS. Endoscopic transnasal transclival odontoidectomy: a new approach to decompression: technical case report. Neurosurgery. 2008; 63: ONSE92-4. DOI: 10.1227/01.NEU.0000313115.51071.D5

109. Cavallo LM, Messina A, Gardner P, Esposito F, Kassam AB, Cappabianca P, de Divitiis E, Tschabitscher M. Extended endoscopic endonasal approach to the pterygopalatine fossa: anatomical study and clinical considerations. Neurosurgical focus. 2005; 19: E5. DOI: 10.3171/foc.2005.19.1.6

110. Solari D, Magro F, Cappabianca P, Cavallo LM, Samii A, Esposito F, Paternò V, de Divitiis E, Samii M. Anatomical study of the pterygopalatine fossa using an endoscopic endonasal approach: spatial relations and distances between surgical landmarks. J Neurosurg. 2007; 106: 157-63. DOI: 10.3171/jns.2007.106.1.157

111. Kassam AB, Vescan AD, Carrau RL, Prevedello DM, Gardner P, Mintz AH, Snyderman CH, Rhoton AL. Expanded endonasal approach: vidian canal as a landmark to the petrous internal carotid artery. J Neurosurg. 2008; 108: 177-83. DOI: 10.3171/JNS/2008/108/01/0177

112. Zanation AM, Snyderman CH, Carrau RL, Gardner PA, Prevedello DM, Kassam AB. Endoscopic endonasal surgery for petrous apex lesions. Laryngoscope. 2009; 119: 19-25. DOI: 10.1002/lary.20027

113. Madani G, Beale TJ, Lund VJ. Imaging of sinonasal tumors. Semin Ultrasound CT MR. 2009; 30: 25-38. DOI: 10.1053/j.sult.2008.10.013

114. Fatterpekar GM, Delman BN, Som PM. Imaging the paranasal sinuses: where we are and where we are going. Anat Rec (Hoboken). 2008; 291: 1564-72. DOI: 10.1002/ar.20773

115. Yousry I, Moriggl B, Schmid UD, Naidich TP, Yousry TA. Trigeminal ganglion and its divisions: detailed anatomic MR imaging with contrast-enhanced 3D constructive interference in the steady state sequences. AJNR. 2005; 26: 1128-35.

116. Maroldi R, Ravanelli M, Borghesi A, Farina D. Paranasal sinus imaging. Eur J Radiol. 2008; 66: 372-86. DOI: 10.1016/j.ejrad.2008.01.059

117. Strauss G. Computerassistierte Chirurgie an der Rhinobasis [Computer-assisted surgery of the frontal skull base]. HNO. 2009; 57: 990-7.

118. Caversaccio M, Zheng G, Nolte LP. Computerassistierte Chirurgie der Nasennebenhöhlen und der vorderen Schädelbasis [Computer-aided surgery of the paranasal sinuses and the anterior skull base]. HNO. 2008; 56: 376-82. DOI: 10.1007/s00106-008-1705-2

119. Strauss G, Winkler D, Trantakis C, Schulz T, Meixensberger J. Aufbereitung radiologischer Daten zur präoperativen Planung in der Schädelbasischirurgie [Post-processing of radiological data for preoperative planning in skull base surgery]. Laryngorhinootologie. 2004; 83: 157-63.

120. Schipper J, Klenzner T, Berlis A, Maier W, Offergeld C, Schramm A, Gellrich NC. Objektivierung von Therapieergebnissen in der Schädelbasischirurgie durch virtuelle Modellanalyse [Objectivity of therapeutic results following skull base surgery using virtual model analysis]. HNO. 2006; 54: 677-83. DOI: 10.1007/s00106-005-1352-9

121. Isaacs S, Fakhri S, Luong A, Citardi MJ. Intraoperative imaging for otorhinolaryngology-head and neck surgery. Otolaryngol Clin North Am. 2009; 42: 765-79, viii. DOI: 10.1016/j.otc.2009.08.014

122. Lohnstein PU, Schipper J, Berlis A, Maier W. Sonographisch unterstützte computerassistierte Chirurgie (SACAS) in der Orbitachirurgie [Sonography aided computer assisted surgery (SACAS) in orbital surgery]. HNO. 2007; 55: 778-84. DOI: 10.1007/s00106-006-1500-x

123. Leach P, Abou-Zeid AH, Kearney T, Davis J, Trainer PJ, Gnanalingham KK. Endoscopic transsphenoidal pituitary surgery: evidence of an operative learning curve. Neurosurgery. 2010; 67: 1205-12. DOI: 10.1227/NEU.0b013e3181ef25c5

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