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

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 pro-
duce results comparable to those of open surgical ap-
proaches 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 resec-
tion of malignant neoplasms doesn’t compromise the
oncological results as long as the completeness of the
ablation is proven by histological evaluation of the resec-
tion 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 well 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, vascular-
ization, form, structure, or the extradural locoregional
extension, invasion of vessels, meningeal infiltration or
intradural growth are general contraindications for en-
doscopic 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 ap-
proach 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 expos-
tion of anatomical landmarks, the avoidance of soiling
of the endoscope and restriction by multiple instruments
– thus the warranty of an unobstructed view on the sur-
gical 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-dimension-
al” 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 sphenoidale 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 micro-
scopic 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 debulk-
ing usually depend on its consistency – bimanual suctions,
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 catastrophic 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 ob-
served 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) aequous 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 allogeneic and xenogeneic 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 fibringlue [39], [40]. Nevertheless, some papers also report good result without its use [35], [38].

#### 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 be 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 Amikacin 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 convalescence, 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 meningi-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 reconstruction 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 rhinoliquorrea, 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 | 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 | 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 septom 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 cm² [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 cm² [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 cm² [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 cranio cervical 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 be enlarged using a drill [101]. The posterior wall of the maxillary sinus is then removed endonasally and the palate 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 cm² [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
  - Panchlival
- 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.

4.2 Extended endonasal approaches – sagittal plane

The sagittal plane extends from the frontal sinus to the second vertebra and enables approach through the chrea 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 ethmoidectomy. It is important to assure that the bony septa of the ethmoid are completely removed up to the ethmoid roof and the cribiform 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 chrea 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 Ila), resection of the frontal sinus floor lateral to the nasal septum (Draf Ib), 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 chresta 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 trans-sellar 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. Here 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],
The petrous apex [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 paracervical 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 paracervical 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 pre-pontine 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.

Infra petrosal

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, trans hypoglossal, 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...
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 otolaryngologist 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.

### 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  | Medial orbital decompression              |
|            | Optic nerve decompression                 |
|            | Sella/ pituitary (extrasellar)            |
|            | Petrous apex (medial part)                |
|            | Transclival approach (extradural)         |
|            | Transdental approach (extradural)         |
| Level IV   | A. Intracranial extension                |
|            | Transplanum approach                     |
|            | Transcribriform approach                  |
|            | Neoplasm rostral of pituitary stalk       |
|            | Transplanum approach                     |
|            | Transcribriform approach                  |
|            | Neoplasm of pituitary stalk               |
|            | Neoplasm dorsal of pituitary stalk        |
|            | Transclival approach                      |
|            | Foramen magnum approach                   |
| Level V    | A. Middle coronal plane (paramedian)      |
|            | Suprapetrous approach to ICA              |
|            | Infrapetrous approach to ICA              |
|            | Transpetrygoid approach                   |
|            | Infra temporal approach                   |
|            | B. Posterior coronal plane (paramedian)   |
|            | C. Vascular surgery                       |

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