# Interdisciplinary Management of Skull Base Tumors



Authors
Ruediger Gerlach[1], Claudia Lodovica Modesti[2], Vittorio Rampinelli[2]

Affiliations
1 Klinik für Neurochirurgie, Helios Klinikum Erfurt GmbH, Erfurt
2 Unit of Otolaryngology and Head and Surgery, ASST Spedali Civili di Brescia, University of Brescia, Italy

Keywords
Skull base surgery, endoscopic surgery, interdisciplinary management

Bibliography
Laryngo-Rhino-Otol 2024; 103: S28–S42
DOI 10.1055/a-2196-8984
ISSN 0935-8943

Georg Thieme Verlag KG, Rüdigerstraße 14, 70469 Stuttgart, Germany

Correspondence
Ruediger Gerlach MD
Department of Neurosurgery
Helios Klinikum Erfurt
Nordhaeuser Str. 74
99089 Erfurt
Tel.: +49 (0) 361 781 2261, Fax: +49 (0) 361 781 2262
ruediger.gerlach@helios-gesundheit.de

## ABSTRACT

**Objective** Endoscopic endonasal skull base surgery has gained acceptance worldwide. Comparative analysis has demonstrated that endoscopic skull base surgery may have advantages for many pathologies of the anterior skull base, e. g., sinonasal malignant tumors; pathologies of the central skull base, e. g., pituitary adenomas, craniopharyngiomas; well-selected cases of planum sphenoidale and tuberculum sellae meningiomas; or for clival lesions, e. g., chordomas, chondrosarcomas, or selected meningiomas. Over the past three decades, interdisciplinary surgical teams, consisting of otolaryngologists and neurosurgeons, have provided detailed anatomical knowledge, suggested new approaches or modifications of established surgical techniques, and offered continued surgical education.
**Method** A review of pertinent literature was conducted with an emphasis on interdisciplinary endoscopic surgery of skull base lesions.
**Results** Based on the authors' surgical experience in two different interdisciplinary endoscopic skull base centers, the authors classify approaches for endoscopic endonasal skull base surgery, describe indications, and key anatomic landmarks for common pathologies, and highlight surgical techniques to avoid complications.
**Conclusion** Interdisciplinary endonasal endoscopic surgery combines surgical expertise, improves resection rates for many pathologies, and minimizes morbidity by reducing the incidence of surgical complications.

## Contents

## 1. Introduction

Transnasal endoscopic techniques have brought significant advancements to skull base surgery. In the last 30 years, our understanding of skull base anatomy from an endoscopic perspective has significantly improved, thus enhancing the value of endoscopic transnasal surgery for treating skull base pathologies [1–3].

As the surgical corridors to the skull base are the nasal cavity and the pneumatized sinuses, otolaryngologists (ENTs) drove much of the development of endoscopic skull base surgery in the very early stage. However, the new technique allowed neurosurgeons access to the skull base form below in a less traumatizing procedure and in many centers all over the world a very close collaboration of ENT surgeons and neurosurgeons started with interdisciplinary surgery addressing pathologies of both sides of the skull base. This interdisciplinary teamwork fostered the further development of special instruments and refinement of surgical approaches and improved patients' outcome.

The endoscopic surgical revolution began in different centers in the world with pituitary surgery and has expanded to various approaches, reaching areas like the parasellar region, the petrous apex, the jugular foramen, the infratemporal fossa, and the upper parapharyngeal space [4–7].

The new techniques clearly demonstrated comparable or superior results in terms of adequacy of resection and reconstruction, while reducing the typical high morbidity of open approaches [8]. The choice of the surgical approach is guided by the type and location of the disease, its relationship with critical neurovascular structures, the biology of the lesion treated, and the characteristics of the expected defect. The surgical exposure must be balanced based on the need of a clear view of the area of interest, the possibility of a complete ablative surgical phase, proper reconstruction, and avoidance of complications. Several endoscopic techniques can be conceived as modular approaches with incremental grades of surgical invasiveness, thus allowing the surgeon to expand the approach in case the lesion extends unexpectedly, in order to identify and protect vital neurovascular structures [3, 9].

Considering the complexity of the anatomy involved, simplifying the intricate geometry into a reliable schematization is necessary for creating a mental map of skull base anatomy. Surgical modules categorized based on their relation with the internal carotid artery in sagittal and coronal planes, provide access to the entire ventral skull base. Sagittal plane approaches give exposure of median structures extending from the posterior plate of frontal sinus to C2, between the internal carotid arteries and orbits [9–11]. These modules include the following approaches: transfrontal, transcribriform, transplanum–transtuberculum, transsellar, transclival, and transodontoid (▶ **Table 1**) [5, 6, 9]. Paramedian and lateral skull base approaches on the coronal plane include various depths of dissection to the lamina papyracea, orbital roof, and orbital cavity, parasellar area, cavernous sinus, superior petrous apex, Meckel's cave, and pterygopalatine and infratemporal fossa. The most posterior coronal approaches provide exposure of the inferior petrous apex, lateral craniocervical junction, and upper parapharyngeal space. The abovementioned approaches are linked together and can be combined based on the need to control a wide variety of pathologies [10]. Moreover, in extended cases, the transnasal route can be combined with other approaches (i. e. transoral, transorbital, transcervical, and transpetrosal), integrated in a multiportal surgical strategy or staged procedures may be indicated in particular cases [12–13].

Given the intrinsic rarity of skull base lesions, the learning curve of the team is slow and needs continuous efforts to develop. For these reasons, patients with skull base pathologies should be referred to dedicated centers with a high surgical expertise, a high caseload and all the availability of all specialties e. g.(neuro)radiologists, medical and radiation oncologists, ophthalmologists, maxillofacial surgeons, and dedicated pathologists.

As multidisciplinary collaborative management of skull base pathologies by ENT surgeons and neurosurgeons is crucial, the aim of this contribution is i) to give an overview of various surgical approaches with emphasis of surgical anatomy and tips and pearls of complication avoidance; ii) to provide evidence of the superiority of patient's outcome if treated by a interdisciplinary endoscopic skull base team [14].

## 2. Methods

The authors used their surgical experience to describe typical surgical endoscopic skull base approaches and demonstrate representative cases. The scientific literature is analyzed to provide a broad understanding of skull bas anatomy, surgical anatomy, and adequacy of approaches with limits and potential complications.

### 2.1 General surgical considerations of interdisciplinarx endoscopic skull base surgery

Adequate preoperative surgical imaging must delineate the anatomical location, the size and the extension of the pathology. Therefore, thin sliced CT scans and MRI with dedicated sequences (eg. fat saturation, thin sliced T2 sequences etc.) are necessary for surgical planning. Usually, image guided surgery is applied for better intraoperative orientation and identification of critical neurovascular structures. In case with optical image guidance, a rigid head fixation is required while electromagnetic navigation may allow head positioning in a head rest and intraoperative movement of the head.

▶ **Table 1** Classification of skull base endoscopic approaches.

| | |
|---|---|
| **Midline approaches** | Transfrontal, Transcribriform, Transplanum–transtuberculum, Transsellar, Transclival, Transodontoid |
| **Coronal approaches** | Approaches to the orbit, Optic decompression, Transcavernous Approach to the medial petrous, apex Transpterygomaxillary and Infratemporal fossa, Upper and lower transpterygoid Suprapetrous (Meckel's cave) approach, Infrapetrous approach, Transcondylar – Transjugular tuberculum Approaches to the upper parapharyngeal space |

▶ **Fig. 1** The patient is placed in a supine position with the upper part of the body slightly elevated (max. 20 °). The head is sharply fixed in a Mayfield clamp in neutral position with a minimal rotation (10 °) towards the main surgeon.

The patient has general anesthesia with orotracheal intubation. A standard anesthesiological preparation of the patient is done including placement of an arterial line for continuous blood pressure monitoring, urinary catheter for fluid balance monitoring, and placement of intravenous devices for sufficient fluid replacement. Intermittent pneumatic compression (IPC) devices are used to help prevent deep venous thrombosis.

A pharyngeal tamponade is placed to prevent aspiration of blood or flushing solution. The anesthesiology team and the monitoring equipment is placed at the patients' feet or head during the operation.

Depending on the pathology endoscopic skull base surgery is performed either by ENT surgeons if no dura invasion is assumed, according to the preoperative MRI. If intracranial extension of the pathology is expected or proven by preoperative imaging, a dedicated interdisciplinary team of ENT surgeons and neurosurgeons should perform surgery interdisciplinary.

The patient is placed in a supine position with the upper part of the body slightly elevated (max. 20 °). The head is either placed on a head rest or sharply fixed in a Mayfield clamp in neutral position with a minimal rotation (10 °) towards the main surgeon (▶ **Fig. 1**).

CT and/ or MRI data are applied for co-referencing and image guidance during surgery. After the preparation of the surgical field xylometazoline soaked paddies are placed in both nostrils for mucosal decongestion. Meanwhile, a sterile draping and a standardized time out are performed. Intravenous antibiotic medication (e. g. 1.5g cefuroxime) is given before surgery starts.

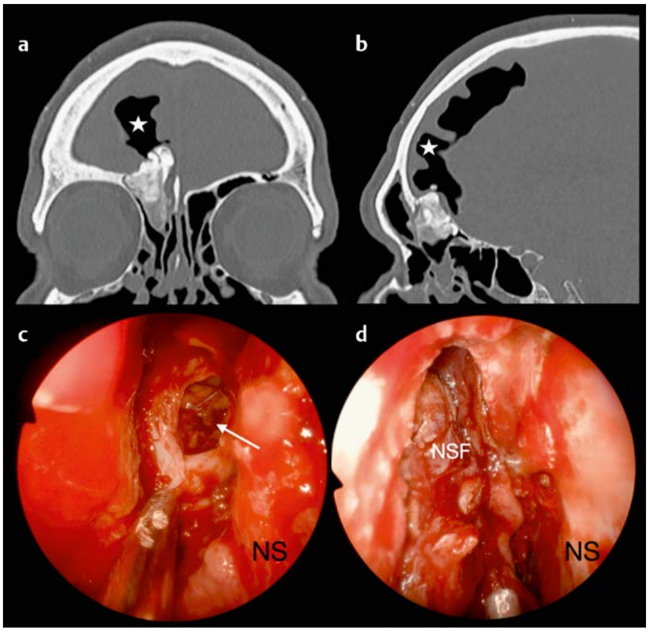
Intraoperative set up may vary according to the surgeon's preference. In our setup, the operating surgeon is standing on the patient's right side while the assisting surgeon is standing on the patient's left side. The scrub nurse is standing next to the main surgeon either on his left or right side. Other teams propagate that both surgeons stand close next to each other on the patient's right side. The mutual positions of surgeons depend on the habits of the team and are all valid when an effective 4 hands surgical technique is guaranteed.

As visualization is mandatory monitors must be placed for continuous unobstructed view without disturbing the ergonomic workflow during surgery for both surgeons and the scrub nurse.

## 2.2 Midline approaches

### 2.2.1 Transfrontal approach

The frontal sinus can be used as a corridor to access the posterior plate of the frontal bone [15–18]. The lesions that mainly arise from this subsite are osteomas, inverted papillomas, glomangiopericytomas, mucoceles and meningoencephaloceles, followed by dermoid cysts and nasal gliomas [16, 19–21]. The exposure phase of the endoscopic transfrontal approach consists of harvesting a corridor corresponding to a Draf Type III (or IIb in selected monolateral cases) sinusotomy. The anatomical boundaries of the approach are: the nasal bones and anterior plate of the frontal bone, anteriorly; the cribriform plate and nasal septum, posteriorly; the medial and cranial portions of the orbits, laterally. Lesion with far lateral frontal extension and involvement of the anterior frontal plate can be rarely managed with a pure endoscopic transfrontal approach, since an exposure allowing a satisfactory surgical maneuverability cannot be reached. In these cases, pure open or combined strategies can be performed. Furthermore, dysembriogenic lesions show typical extensions toward the external nose, so a combined endoscopic or open rhinoplasty technique might also be recommended for specific cases [16]. The lateral exposure over the meridian of the orbit, traditionally considered the lateral limit of the endoscopic transfrontal approach, can be expanded through an orbital transposition. This consist in the sectioning of the anterior ethmoidal artery, which allows the inferior and lateral dislocation of the orbit and lateral gain of precious millimeters [22]. This surgical path is particularly challenging, thus limiting its use to selected cases. The area of exposure is limited and constant, especially laterally. The anatomy of the patient really influences the surgical maneuverability: a narrow corridor in the anteroposterior direction limits the movements of the surgeons, and 4 hands dissection may not be applied. The damage of the anterior frontal tissues, orbit and cribriform plate may lead to esthetic and severe functional complications. Transdural dissection is particularly complex due to the geometry of the defect and angle of approach, as well as the presence of delicate vascular structures (i. e. superior sagittal sinus, bridging veins, and orbitofrontal and frontopolar arteries). Finally, but not less important, the reconstructive phase is hampered by different factors. The anterior positions make the anterior and upper border of the frontal endoscopic craniectomy difficult to be reached by posterior pedicled mucosal flaps (nasoseptal flap). Since the orientation of the defect is vertical, the intracranial pressure, combined with gravity, does not push perpendicularly on the duroplasty, thus reducing its stability. Despite the rarity of indications and the intrinsic complexity, it is crucial to master this approach to manage lesions located in the far-anterior region of the midline skull base. Furthermore, a secondary involvement for contiguity of this area is quite common for lesions originating from near-




▶ **Fig. 2** Case of anterior skull base osteoma, centered on the posterior plate of the frontal bone, with intracranial extension and valve mechanism and pneumoencephalon (white stars in figure **a** and **b**). Image **c** shows the dural defect, obtained with a transfrontal endoscopic approach (white arrow). Reconstruction was performed in multilayer fashion, with intradural fat, intracranial extradural fascial lata, and nasospetal flap (NSF in D). NS – Nasal Septum.

by skull base areas, such as the cribriform plate and ethmoidal roof [23] (▶ **Fig. 2**).

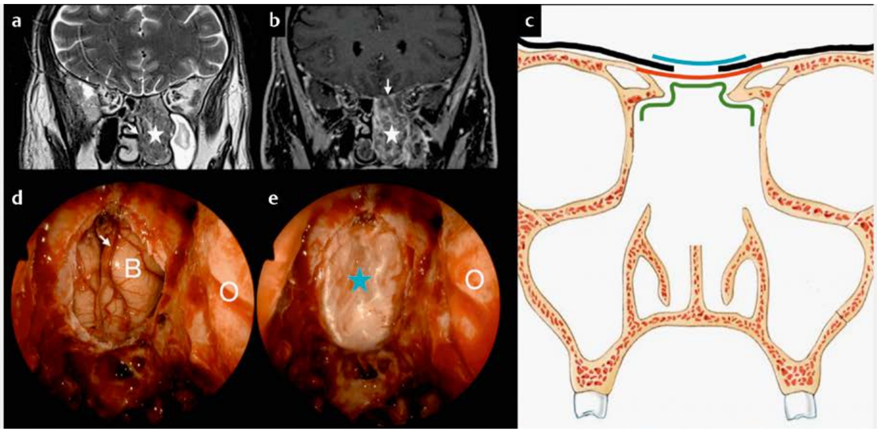
### 2.2.2 Transcribriform approach

The transcribriform approach is conceived to endoscopically remove anterior skull base lesions involving the cribriform plate and the ethmoidal roof (also named fovea ethmoidalis) [5, 24]. Over the last 20 years, this surgical route has been the primary technique for treating various diseases, such as sinonasal malignancies, meningoencephaloceles, meningiomas [25–29], schwannomas [30, 31], and dysembryogenic lesions [32]. Moreover, selected spontaneous or post-traumatic cerebrospinal fluid leaks may be treated with a tailored transcribriform route. The main malignant histologies addressed with this approach are squamous cell carcinomas, adenocarcinomas (mainly intestinal type or non-intestinal type), and olfactory neuroblastomas [1, 10, 33–42], with good oncologic results and minimal morbidity when compared with traditional open approaches. Among the factors influencing the choice of the approach, besides the biological behavior of the lesion, local extension, and reconstructive options, the pre-surgery olfactory status and preservation possibilities must be considered [43–45]. The boundaries for the transcribriform route include the angle between the posterior frontal plate and the anterior skull base anteriorly, the connection of ethmoid and sphenoid planum posteriorly, and the medial orbital walls laterally. Based on local extension, in selected cases, the resection can be enlarged over these limits, above the orbits, on the planum sphenoidalis, and on the posterior plate of the frontal sinus. Moreover, unilateral endoscopic craniectomy can control selected monolateral lesion, not crossing the nasal septum [46]. This surgical strategy, in parallel with good oncologic results once a complete resection is achieved, allows patients to partially maintain the sense of smell. In contrast, bilateral resections are followed invariably by anosmia, since the olfactory organs (fila, bulbs, and tracts) are cut on both sides. The first phase of surgery consists of the exploration of the nasal fossa to understand local extension and debulking of the lesion. To expose the anterior skull base, a bilateral medial maxillectomy, complete ethmoidectomy, Draf III procedure, transrostral sphenoidotomy, and septectomy are performed. The bilateral approach allows for a dual nostril, four-hands technique. Once the bony anterior skull base is exposed, the ethmoidal arteries must be coagulated and cut. The anterior (and middle if present), usually runs extracranially, while the posterior runs in a bony canal between the cribriform plate and planum, which has to be drilled to expose the artery before the coagulation. Once the area of interest is exposed, the craniectomy is performed. The resection can be extended to the dura, falx, and olfactory bulbs and tracts if necessary. This technique provides a clear view of the gyrus rectus and medial orbital gyrus, which can be addressed endoscopically too in case of modest infiltration. During the intracranial phase, vessels like the anterior falcine artery and frontopolar artery must be managed carefully, to avoid injuries that may need to be controlled with an open approach [47].

To date, multilayer reconstruction using various grafts and flaps represents the gold standard [48, 49]. The geometry of the defect, with gravity and intracranial pressure pushing on the margins of the plasty, as well as the rigid buttress offered by the bony boundaries of the resection, allows for a stabilization of the different layers of the reconstruction. This determines the low rates of postoperative cerebro-spinal fluid leak reported in the literature. Fascia lata/iliotibial tract, synthetic, or hetero-grafts, in combination or not with fat grafts, are usually used for the intracranial intradural and extradural layers of the reconstruction. As second or third layer, vascularized mucosal pedicled flaps offer an optimal option, minimizing leaks and crusting formation. However, since nasal-ethmoidal tumors have the propensity to affect the nasal septum and turbinates, local vascularized flaps are often unavailable. In these cases, the use of a third extracranial fascial layer demonstrated good results in several experiences in the literature (▶ **Fig. 3**).

### 2.2.3 Transsellar approach

Indications for the transsellar approach are mainly sellar pathologies with pituitary adenomas being the most frequent encountered lesion. However other intra – or suprasellar lesions may be operated via the transsellar approach, eg. craniopharyngiomas with limited suprasellar extension. Other rare pathologies may be metastatic tumors or lymphomas. According to Cappabianca [50] the surgical ablative procedure is divided into 3 phases, the nasal, the sphenoidal and the sellar phase and is carried out in a very standardized way. The approach should be as minimal as possible to get an adequate exposure of the pituitary adenoma or any other lesion, the pathology should be removed with preservation of the pituitary gland and a thorough reconstruction has to be performed with closure of the defect.




▶ **Fig. 3** Case of a naso-ethmoidal intestinal type adenocarcinoma (white stars in figure **a** and **b**). The lesion invaded the nasal septum (white arrow in **a**) and had a critical contact on the left lamina cribrosa (white arrow in **b**). A bilateral transcribriform approach was therefore performed. Image **d** shows the dural defect, with brain (**B**) exposed and frontal vessels (white arrow). Image **e** shows the fascia lata of the intradural reconstruction (blue star). Image c depicts the multilayer reconstruction with 3 strata of fascia lata. The first (blue) is positioned intradurally, the second (red) is intracranial extradural, the third (green) is extracranial. O – Orbit.

### 2.2.3.1 Nasal phase

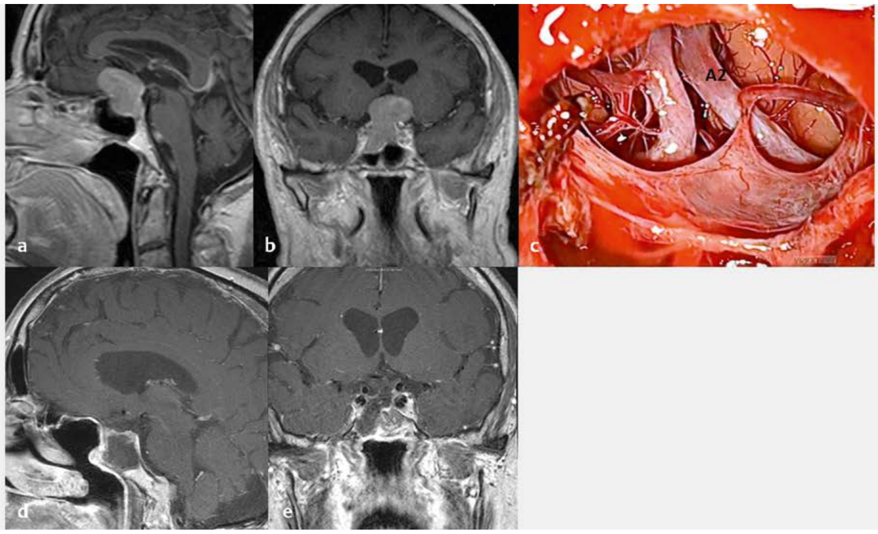
The operation starts after endoscopic inspection of both nostrils using a 0° endoscope. For standard pituitary tumors, a mononostril approach may be performed without the use of a speculum. Some authors prefer a binostril approach [50, 51]. Other surgeons propagate the mononostril endonasal transethmoidal-paraseptal approach to resect pituitary adenomas [52]. In our experience, the mononostril approach provides sufficient surgical freedom. Dissection is done using the three or four hands technique. In the nasal phase the surgeon usually holds the endoscope in his left hand while the dissecting instruments are used with his right hand. With this technique a more dynamic view is provided to assess depth perception. The assistant surgeon uses suction and clears the endoscope from debris using on demand irrigation. In our interdisciplinary team the ENT surgeon starts surgery with neurosurgical assistance. After the endoscope has been introduced into the nose some landmarks guide the further procedure. The endoscope is advanced between the inferior turbinate and the nasal septum and the choana is identified. The sphenoid ostium may by localized very early by elevating the endoscope about 1.0 cm cranial to the choana. The middle turbinate is identified. The standard approach includes a gentle lateralisation of the middle turbinate to enlarge the room between the middle turbinate and the nasal septum and to increase the surgical freedom in the chosen nostril. Care should be taken during lateral luxation of the turbinates, in order to avoid ethmoidal plate injuries which may result in cerebrospinal fluid (CSF) leak. If the sphenoid ostium is covered by either the superior or the supreme turbinate, these can be gently lateralized or removed. We use circular punches to enlarge the ostium and then one can already visualize the ipsilateral sphenoid sinus. From the medial circumference of the sphenoid ostium the mucosa is incised by a straight upward directed incision towards the posterior part of the nasal septum. Prior to the incision saline may be injected to elevate the mucosa at the posterior part of the nasal septum. A monopolar cautery or a sickle knife can be used for mucosal incision. In cases with extended approaches or suspected high flow CSF fistula a pediculized flap on the sphenopalatine artery is dissected according to the size of defect as described [53]. The posterior part of the nasal septum is pushed to the contralateral side. The contralateral mucosa is elevated, and the contralateral ostium is exposed.

### 2.2.3.2 Sphenoid phase

An anterior sphenoidectomy is performed with the use of a 4mm diamond drill. It is crucial to widely expose and open the anterior face of the sphenoid in order to gain a proper working angle for all the instruments when inside the sphenoid with their tips in the sella. If necessary, the inferior part of the ipsilateral superior turbinate may be removed and a limited posterior ethmoidectomy may be performed to extend the degree of surgical freedom. After the anterior sphenoidectomy (removal of the rostrum) has been completed, the intrasphenoid septae are removed using a diamond drill. It is recommended to spare the bony septa for later reconstruction of the sellar floor. The mucosa is elevated and lateralized or partially resected. If multiple septae are present, especially horizontal septa, the use of image guidance may help to define the extent of exposure with the exposition of the planum sphenoidale as the most cranial landmark. In all cases the bilateral bony prominence of the carotid arteries and optocarotid recesses are used as landmarks for identifying the sellar floor (▶ **Fig. 5**).

### 2.2.3.3 Sellar phase

After completing the sphenoid phase, the neurosurgeon and the ENT surgeon may switch positions and the neurosurgeon continues to perform the surgical procedure while the assistant surgeon drives the endoscope. We do not use an endoscope holder during surgery as we feel a dynamic endoscopy may increase the surgeons' comfort and the flexibility during intrasellar dissection. Bimanual dissection is performed. Opening of the sellar floor is performed using a diamond drill. In cases were the sellar floor is thinned out a hook or dissector may be used to open the floor. The extent of opening reaches from the base of the sella to the planum sphenoidale and from one carotid prominence to the contralateral ca-




► **Fig. 4** rostrally extending inactive pituitary macroadenoma which was operated via a transplanum transtuberculum approach. Preoperative contrast enhanced MRI sagittal **a** and coronal **b** plane, **c** intraoperative supradiaphragmatic view displaying both A2 arteries (A2) and in the anterior interhemispheric fissure.

rotid prominence. Care has to be taken not to injure the carotid artery as in some occasions no bony coverage of the carotid artery is present. After removal of the bone a straight sharp dura incision at the basal part of the sella is performed. The dural opening is enlarged cranially on both sides laterally using microscissors. Bleeding from the intercavernous sinus or the cavernous sinus may be stopped with Floseal or bipolar coagulation. Long straight formed instruments are used to manipulate through the nose and the tip of the instrument should always be visualized during each step of surgery. The size of the tumor and the preoperative tumor location determines the dissection strategy. In microadenomas the surgeon identifies the tumor according to the preoperative MRI and a selective adenomectomy is performed. Identification of a pseudocapsule may facilitate extracapsular dissection [54]. In macroadenomas tumor dissection usually starts at the basal part of the tumor. Intratumoral debulking may facilitate the identification of the pseudocapsule and allows subsequent extracapsular dissection. With various angled curettes a stepwise bimanual dissection in a caudal to cranial direction is performed. With the suction in one hand and the curette in the other hand the surgeon may dissect with only gentle traction while counter traction is applied, as it is usually applied during transcranial microsurgical procedures, avoiding tearing of neurovascular structures or the arachnoid at the sellar entrance. The medial wall of the cavernous sinus has to be identified. Once the intrasellar tumor has been removed, the suprasellar tumor has to be progressively removed. The early identification of the diaphragm may prevent CSF fistula. Caution has to be given to differentiate residual tumor from normal pituitary gland. The gland is usually more yellow and differs from its consistency. If the tumor removal is felt to be complete, the angled endoscope should be applied to have a panoramic view into all directions in order to confirm that no residual tumor is left behind. If a cavernous sinus infiltration is detected on preoperative MRI [55] the tumor resection may be continued by either just following the tumor with the curette or by removing the medial wall of the cavernous sinus [56]. The main concerns of tumor resection within the cavernous sinus are carotid artery injury and cranial neuropathies. Differences in the extent of resections are described depending on whether the tumor extends into the superior cavernous sinus (Knosp 3A) and into the inferior cavernous sinus (Knosp Grade 3B) [57]. For tumors extending into the superior cavernous sinus, rates of endocrine remission/gross-total resection were significantly higher in grade 3A than in grade 3B pituitary adenomas [57]. In Knosp Grade 1–3 adenomas, histological assessment of the medial cavernous sinus wall confirmed invasion in 93 % of nonfunctional adenomas and in 83 % of functional adenomas and all tumors could be completely removed [58]. Safe techniques to maximize the extent of resection through the medial CS wall while minimizing the risk of cranial neuropathy and blood loss have been described by several groups [56, 59]. If the principles of gentle dissection under constant visualization are applied patients with secreting adenomas (GH- adenomas and ACTH- adenomas) may benefit from the resection of medial cavernous sinus tumor extensions without increased morbidity or mortality. If tumors extend into the lateral cavernous sinus compartments, adjuvant treatment strategies (e. g. radiosurgery) may be necessary and resection should be performed by experienced surgeons.

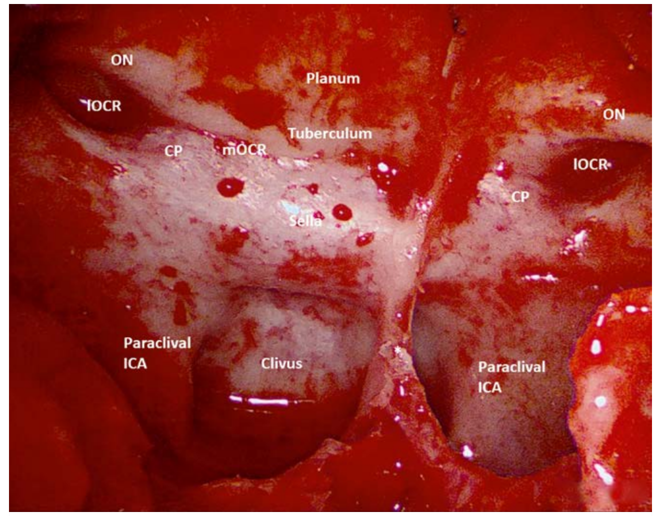
#### 2.2.3.4 Closure and reconstruction techniques

According to the size and the growth direction of the pituitary adenoma, the likelihood of an intraoperative CSF fistula, especially a high flow, should be considered in advance. Pituitary adenomas with anterior growth direction and/ or a very large suprasellar tumor extension carry the risk of intraoperative CSF leak, which may require special reconstruction. Therefore, a strategy for proper closure techniques has to be considered before surgery starts. Sometimes it is easier to dissect the pedicled mucochondroperiostial flap during the nasal stage of the operation, especially in patients with abnormalities of the nasal septum, rather than harvesting a rescue flap after resection of a very large suprasellar pituitary adenoma. Preparation and draping of the sites were closure material may be harvested (abdominal fat, fascia lata) is best performed at the start of surgery rather than at a later phase of surgery. Fascia lata is a very robust and safe dural reconstruction material, which may be used as inlay or onlay graft either as autologous transplant or as commercially available material. Fat should be used to fill large dead spaces and bony material, which was removed during the approach, supports the reconstruction if it is lodged against the surrounding bone.

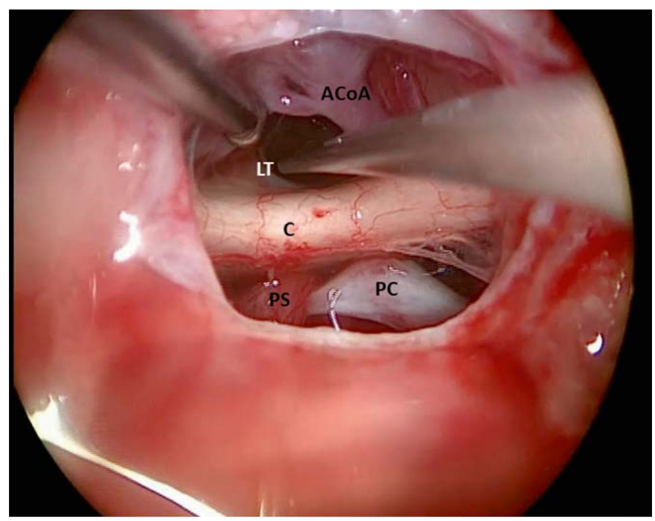
### 2.2.4 Transplanum-tuberculum approach

Rostrally extending suprasellar lesions (▶ **Fig. 4**) and large suprasellar tumors growing toward or in the third ventricle may not be accessible through transsellar approach. Extension of the surgical corridor through the planum sphenoidale and tuberculum sellae have been shown to allow appropriate dissection of those lesions and have advantages over transcranial surgery obviating cosmetic deformity and brain/chiasmal retraction. The rostral extension via endoscopic endonasal transsellar-transtubercular-transplanum approaches can provide a safe and feasible route for suprasellar lesions, in subchiasmatic, suprachiasmatic, and intraventricular regions [60]. Indications for a transplanum transtuberculum approach are large and rostrally extending pituitary adenomas, craniopharyngiomas, meningiomas of the planum and tuberculum sellae. Patient positioning is similar to the position for the transsellar approach with sharp fixiation in the Mayfield clamp and image guidance is used for intraoperative validation of anatomical structures. Check preoperative CT scan for sphenoid sinus anatomy as a conchal type of sinus may require extensive bone drilling. In selected cases intraoperative monitoring using SSEP's and VEP's and monitoring of the oculomotoric cranial nerves may be helpful. The intraoperative use of a micro doppler is recommended to identify the carotid and ophthalmic artery and avoid vascular complications. The approach may be limited by medialized (kissing) carotids with reduced intercarotid distance.

After performing a sellar approach, the bone overlying tuberculum and planum is drilled using a diamond 4-mm burr. Bone drilling is performed rostrally up to the level of the posterior ethmoidal arteries. The olfactory apparatus should be spared and care has to be applied to avoid injury. Important landmarks during surgery are the carotid protuberance, the medial and lateral OCR, the middle clinoid process, the clival recess, the optic nerve, the lateral tubercular crest, the lateral tubercular recess and the distal osseous arch of carotid sulcus [60] (▶ **Fig. 5**). Bone drilling is done to egg shell to planum und tuberculum and careful bone removal is performed using either dissecting instruments or a 1mm 45-degree Kerrison punch. Dural integrity is ensured at all times. Afterwards the bone overlying the optic nerve above and lateral to the sella and the tuberculum is removed using 2-mm and 4-mm diamond drills. Continues irrigation with saline is of importance to avoid thermal damage to the optic nerve. Be aware, sometimes the ICA is with a very thin or even no bony coverage. A strait midline durotomy is performed from caudal to cranial to the level of the superior intercavernous sinus. Than the dura incision in continued above the intercavernous sinus. The intercavernous sinus is cauterized using

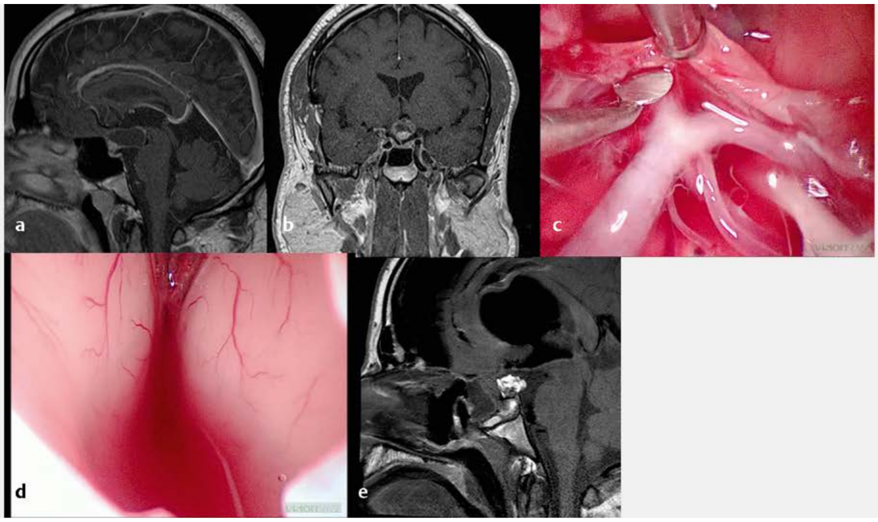



▶ **Fig. 5** bony exposure transplanum transtuberculum approach. IMpartant landmarks are both carotid promineces, the medial and lateral OCR, the tuberculum, the planum. ON optic nerve, lOCR lateral optocarotid recess, CP carotid prominence, mOCR medial optocarotid recess, ICA internal carotid artery.




▶ **Fig. 6** intradural exposure after performing a transplanum transtuberculum approach for a suprachiasmatic approach to a lesion within the third ventricle. C-Chiasm, PS-pituitary stalk, PC posterior clinoid process, ACoA- anterior communicating artery complex, LT- lamina terminalis.

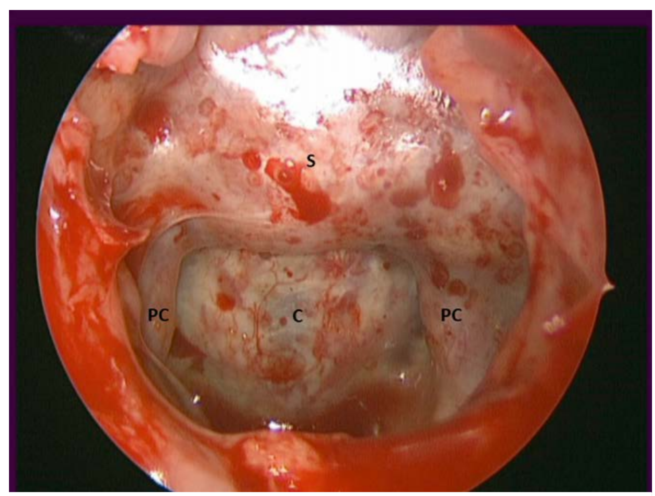
bipolar forceps and sharply divided. If still venous bleeding occurs hemostatic agents (e. g. Floseal) als Verweis auf das Produkt is used to achieve sufficient hemostasis. The dura incision of the planum is slightly curved laterally to both sides and the dural flap is mobilized laterally to identify the carotid artery with its origin of the ophthalmic artery before further extending the incision laterally. The arachnoid of the subchiasmatic cistern is carefully dissected. Care has to be applied to avoid injury to the superior hypophyseal artery branches supplying the chiasm (▶ **Fig. 6**). Tumor removal is performed in bimanual dissection procedure as it is performed by transcranial surgery. The assistant, who has to close-




▸ **Fig. 7** preoperative contrast enhanced sagittal **a** and coronal **b** MRI depicting a recurrent craniopharyngioma after previous transcranial surgery and radiation therapy with extension towards the 3rd ventricle, **c** intraoperative view on the basilar tip with the left posterior cerebral artery and the dissection of the tumor capsula from the right posterior artery, left supracerebellar artery and the left oculomotor nerve, **d** view into the 3rd ventricle after tumor removal displaying the choriod plexus, E postoperative sagittal MRI with fat graft for obliteration of the dead space.

ly follow the dissection steps and helps to identify neurovascular structures, drives the endoscope. Central tumor debulking enables a stepwise extracapsular dissection. Identification of the pituitary stalk and preservation is of importance. Laterally the 3rd nerve may be identified. If the dissection is performed backwards the basilar tip with the ventral brainstem, both posterior cerebral arteries and supracerebellar arteries are encountered (▸ **Fig. 7a–c**). If the lesion extends into the third ventricle a very careful dissection of the ventricular wall and the hypothalamus has to be performed (▸ **Fig. 7d**). A suprachiasmatic dissection may be necessary in lesions with suprachiasmatic extension. Here the anterior communicating artery complex should be identified and injury to the arteries has to avoided. Be aware of the recurrent arteries (e. g. artery of Heuber) (▸ **Fig. 6**).

The closure phase may be particularly challenging, due to the big dimension of the defect and high CSF cisternal flow. In cases of transplanum, transtuberculum approach, a pedicled mucochondroperiostial flap is usually elevated during the nasal stage of the operation. Additionally, preparation and draping of the sites where closure material may be harvested (abdominal fat, fascia lata) is performed at the start of surgery. A lumbar drain is placed before surgery starts and is opened during surgery when the bone is drilled and the dura is incised. A 3-layer reconstruction is usually performed. Fat is placed to fill the dead space. Fascia lata is a very robust and safe dural reconstruction material. It can be used as an inlay plastic and it is placed under the dural rims inside the dura and fixed with a thin layer of fibrin glue. Then a bony reconstruction is performed and when possible, the grafted bone from the sphenoid septae or the nasal septum is lodged against the surrounding bone. If available, a fascia lata piece is placed over the defect as overlay and the vascularized flap is placed to cover the whole defect. For the reconstruction of the nasal septum, the reverse flap and silicon airway nasal splints are used to enhance the healing of the nasal mucosa.

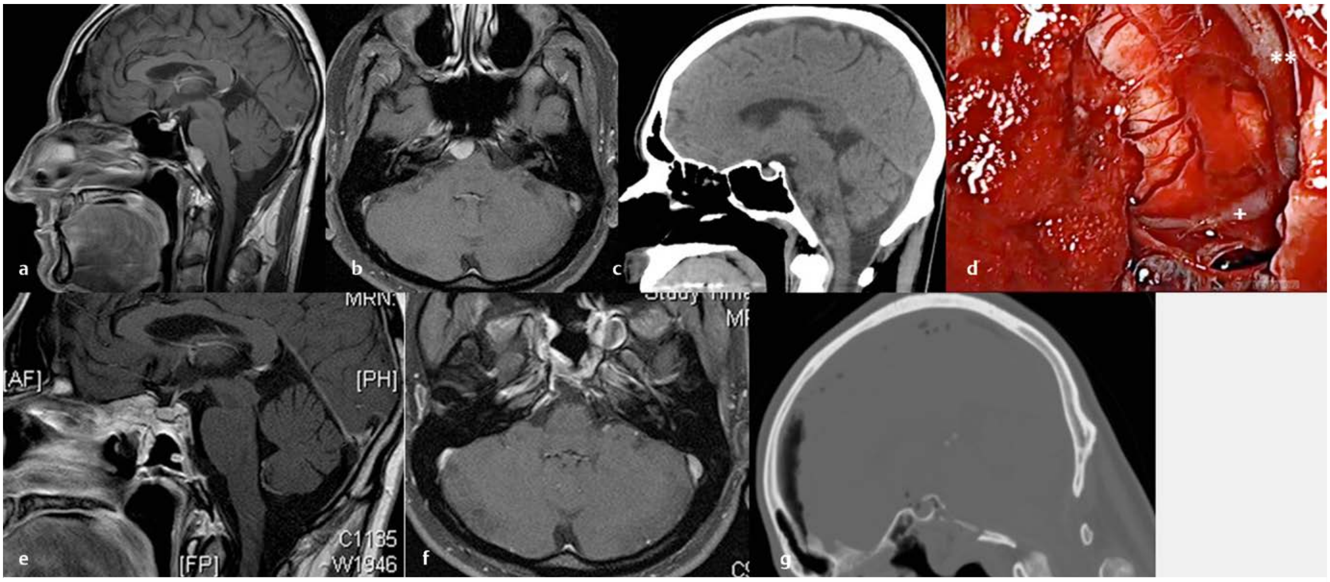



▸ **Fig. 8** intraoperative view of the mid clivus with both paraclival carotid arteries, S- sella, PC paraclival carotid artery, C clivus.

### 2.2.5 Transclival approach

Indications for the transclival approach are sellar lesions with caudal expansion or infrasellar lesions with rostral extension, such us pituitary adenomas, chordomas or chondrosarcomas Selected cases of intradural pathologies of the posterior fossa may also be an indication for transclival approach (eg. (petro)clival meningiomas).

Surgical positioning and preparation is similar to the transplanum, transtuberculum approach. Image guidance should be applied and a binostril dissection technique is recommended. After performing the resection of the anterior wall of the sphenoid sinus in a standardized way using a 4mm coarse diamond drill the floor of the sphenoid sinus has to be exposed. To gain access to the caudal parts of the lesions the choana should be drilled and the sphenoid floor should be thinned to improve the maneuverability of the




▶ **Fig. 9** mid transclival approach for resection of a clival meningioma. Preoperative sagittal **a** and transversal **b** contrast enhanced MRI and preoperative CT scan which demonstrates the relation of the sphenoid sinus to the meningioma **c**, **d** intraoperative view on the ventral pons, * * basisilar artery, + vertebral artery, postoperative sagittal **e** and axial **f** MRT showing complete resection and postoperative CT scan demonstrating the bony reconstruction of the clivus **g**

instruments according to the borders of the lesion by applying image guidance.

Key landmarks for the transclival approach are the sellar floor and the transclival ACI at both sides (▶ **Fig. 8**). The anatomy of the sphenoid sinus must be checked on preoperative CT, hence the degree of pneumatization of the sphenoid sinus may help to evaluate the amount of bone drilling.

The transclival approach can be divided into upper, middle, and lower [61]. For the upper approach, drilling of the sellar face is performed. The sellar dura mater consists of two layers. The outer or periosteal layer spans between the anterior surface of the gland and the parasellar and paraclival ICA, thus forming the anterior wall of the cavernous sinus. The inner/meningeal layer covers the capsule of the gland, at the same time forming the medial wall of the cavernous sinus.

The upper clival approach provides midline access to the interpeduncular cistern, the basilar apex, the mammillary bodies, and the floor of the third ventricle. Access to the interpeduncular cistern and midbrain behind the upper clivus usually requires posterior clinoidectomy, which can be unilateral or bilateral depending on the pathology. Removal of the posterior clinoids most of the times requires transposition of the pituitary gland, which can be done extradurally, interdurally, or intradurally [61]. The interdural pituitary transposition offers a transcavernous sinus approach to paramedian lesions within or behind the parasellar space, such as para/retro/suprasellar extension of chordomas or chondrosarcomas. This approach requires mobilization or sacrifice of the ipsilateral inferior hypophyseal artery [61].

A middle transclival approach provides access to the ventral pons and the prepontine cistern, the basilar trunk and anterior inferior cerebellar artery, as well as the cisternal segment of the abducens nerve (▶ **Fig. 9**). The sphenoidal clivus is limited laterally by the paraclival ICAs, and the petroclival fissure. Laterally, the middle transclival exposure is limited by the interdural segment of cranial nerve VI.

The lower transclival approach through the lower segment of the clivus, which lies below the roof of the choana, exposes the premedullary cistern and ventral medullary surface, the vertebral arteries, vertebrobasilar junction and posterior inferior cerebellar arteries, as well as cranial nerves IX–XII [61]. The lower transclival approach may be applied to lesions of the craniocervical junction and to address pathologies below the foramen magnum to the level of the odontoid. The lower limit of an endonasal lower transclival approach is determined by the hard palate and the nasopalatine line may be used to estimate the lowest extent of resection.

## 2.3 Coronal approaches

### 2.3.1 Medial maxillectomies, pterygopalatine and infratemporal fossae

Coronal approaches offer access to skull base lesions with lateral extension. Different subsites can be considered surgical target in case of direct involvement, as well as "doors" to be crossed to reach posterior lesions. In this view, the anatomical structures of major interest are the maxillary sinus, the pterygoid process, the orbit, the sphenoid walls, the petrous bone, and the occipital condyle.

The maxillary sinus gives access to the pterygopalatine and infratemporal fossae posteriorly, and the approaches encompassing the endoscopic disassembling its medial wall are usually referred as endoscopic medial maxillectomies. These can be classified into 4 types, going from a less invasive to a more invasive resection, following a modular dissection [62].

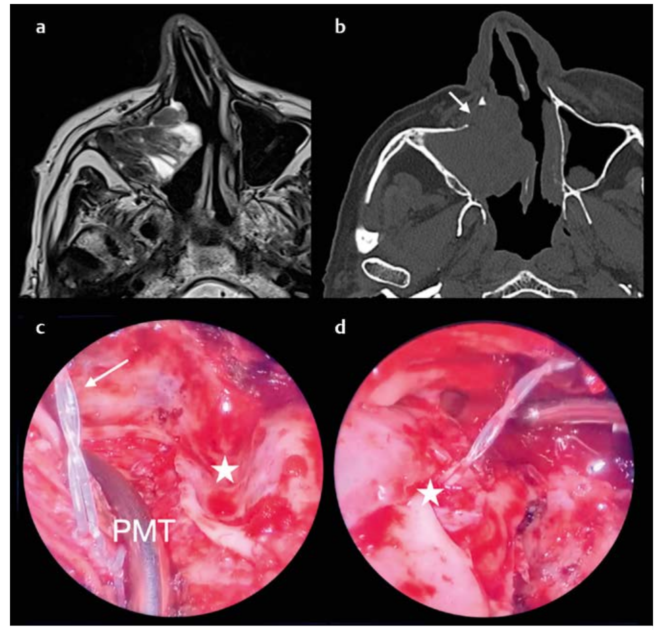
Type A endoscopic medial maxillectomy expects an inferior uncinectomy and has as anatomical boundaries the insertion of the inferior turbinate inferiorly, the orbital floor superiorly, the descending palatine canal posteriorly, and the nasolacrimal duct anteriorly. In Type B endoscopic medial maxillectomy, the inferior turbinate is removed, sparing the Hasner's valve. The portion of the medial wall behind the nasolacrimal duct is completely removed, reaching the floor of the nasal cavity. With Type C maxillectomy, the nasolacrimal duct and the remaining anterior portion of the medial wall are resected. Type D endoscopic medial maxillectomy, also referred as Denker's or Sturmann-Canfield operation, expects the removal of the anteromedial angle of the maxillary sinus, with the infraorbital foramen as lateral limit. The different procedures offer incremental grades of endoscopic exposure, in medio-lateral and cranio-caudal direction. In particular, type D medial maxillectomy provides complete access to the posterior and lateral walls of the sinus, orbit floor, and alveolar and zygomatic recesses. A variation of these procedures is the prelacrimal approach, which consists in the removal of the medial bony edge of the piriform aperture, preserving the lacrimal duct which is displaced medially and repositioned at the end of the procedure [63–67]. This technique reduces the risk of lacrimal stenosis and allows a similar endoscopic view as Type C and Type D maxillectomies, while providing limited working volume and postoperative surveillance.

Once the posterior walls of the maxillary sinus are exposed, infracranial spaces such as the pterygopalatine and infratemporal fossae can be controlled. The first is a narrow cavity whose limits are the pterygoid process posteriorly, the posterior wall of the maxillary sinus anteriorly, the perpendicular process of the palatine bone anteromedially, and the coronal plane connecting the lateral pterygoid lamina and the posterior wall of the sinus (pterygomaxillary fissure), laterally. It is a crossroad between the sinonasal cavity, the infratemporal fossa, and the orbital cavity, containing many neurovascular structures: V2 and pterygopalatine ganglion, along with their branches, and the pterygopalatine tract of the internal maxillary artery with its collateral vessels.

A wide variety of lesions can develop from the pterygopalatine fossa, mainly represented by juvenile angiofibromas [68, 69], vidian and maxillary nerve schwannomas [70–73], fibro-osseous lesions, and hemangiomas [74].

The opening of the fossa starts with the removal of the posterior wall of the maxillary sinus and the perpendicular process of the palatine bone, paying attention not to damage the periosteum. Usually, the dissection is started at the sphenopalatine foramen. The lateral limit of the fossa is found following the infraorbital canal reaching the posterior wall of the maxillary sinus posteriorly [75]. The entrance points the pterygomaxillary fissure. The periosteum is then incised and carefully removed with the underlying fat to expose progressively the pterygopalatine tract of the internal maxillary artery and its collaterals, the nervous structures placed in front of the pterygoid process, and the cranial insertion of the lateral pterygoid muscle on the homonym bony lamina and great wing of the sphenoid. Posteriorly, the vidian nerve and foramen rotundum are exposed once the content of the fossa is removed or transposed laterally [76].

The infratemporal fossa is an anatomical space whose boundaries are the greater wing of sphenoid bone and the squamous portion of the temporal bone superiorly, the lateral pterygoid plate




▶ **Fig. 10** Case of recurrent inverted papilloma of the maxillary sinus, with anterior attachment (images **a** and **b**). Image **b** shows a defect of the anterior wall of the maxillary sinus (white arrow), due to previous transvestibular surgeries. A type **D** endoscopic maxillectomy, encompassing the removal of the anteromedial angle of the maxillary bone was performed. Image **c** shows the premaxillary soft tissues (PMT), partially removed for oncologic reasons, and the complete exposure of the maxillary sinus. The white arrow indicates the alveolar recess, the arrow points the zygomatic recess. The star in image **d** indicates the lacrimal sac, sectioned, with the lacrimal stent passing through.

and the maxillary tuberosity medially, the zygomatic arch, temporal fossa, and the mandibular ramus laterally, and the upper parapharyngeal space posteriorly. It communicates with adjacent spaces: the temporal fossa laterally and the pterygopalatine fossa medially [77, 78]. Due to these close relationships, lesions arising outside the infratemporal fossa can invade it, typically benign lesions from the pterygopalatine fossa. Lesions directly originating from the fossa can spread externally too, like V3 schwannomas and sarcomas [79]. Three dissection corridors within the infratemporal fossa have been described [80]. The lateral corridor exposes the coronoid process through the temporal muscle bellies. The middle corridor reaches the front of the temporomandibular joint, using the space between the temporal and lateral pterygoid muscles. The medial corridor runs between the lateral pterygoid muscle and the lateral pterygoid plate, exposing the mandibular nerve, middle meningeal artery, and the temporomandibular joint.

When dealing with pterygopalatine and infratemporal fossae lesions, the vascularization of the tumor must be considered. In fact, juvenile angiofibromas [69] need preoperative embolization for a safe and complete removal. Therefore, as with almost all clinical entities involving the skull base, multidisciplinary management is crucial, with surgery performed in referral centers equipped with all the necessary facilities [81] (▶ **Fig. 10**).

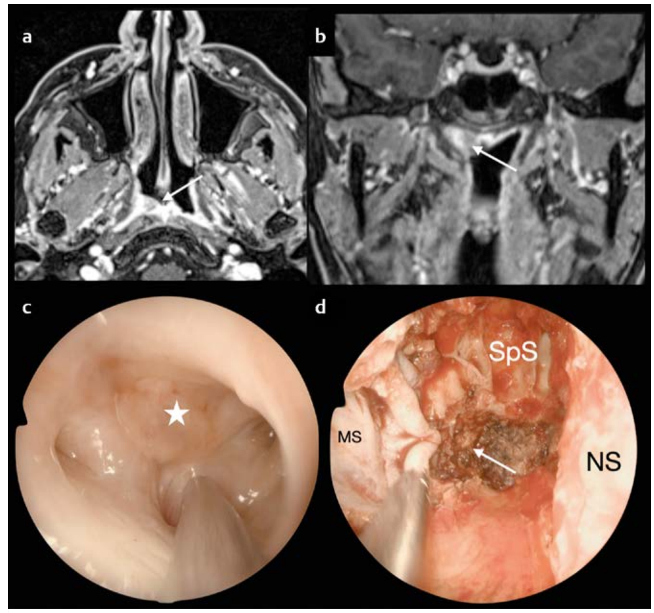
### 2.3.2 Transpterygoid approaches

The dissection of pterygoid process of the sphenoid provides access to several anatomical areas. The upper transpterygoid approach allow reaching the sphenoid floor medially, the greater wing of the sphenoid bone laterally, the superior orbital fissure superiorly, and the scaphoid fossa inferiorly. The lower transpterygoid approach gives exposure of the base of the pterygoid process superiorly, the lateral pterygoid muscle laterally, the pterygomaxillary junction inferiorly, and the nasopharynx medially. The transpterygoid approaches exploit the corridor provided by the maxillary and sphenoid sinuses; thus, a medial maxillectomy (usually type B-C) and sphenoidal opening (usually via a transrostral approach) are usually necessary propaedeutical phases.

Upper transpterygoid approach: The upper transpterygoid approach is usually performed to deal with lesions involving the lateral aspect of the cavernous sinus and Meckel's cave (typically pituitary tumors, meningiomas, and neurogenic tumors), as well as the lateral recess of the sphenoid sinus (typically meningoceles). The approach encompasses the removal of the posterior-medial wall of the maxillary sinus and the orbital process of the palatine bone to expose the contents of the pterygopalatine fossa. Once the neurovascular network is dissected, the contents of the fossa are displaced laterally or removed, based on oncologic needs. The vidian nerve can either be preserved or sacrificed, and it can be used to identify the internal carotid artery at the genu, posteriorly. The inferior orbital fissure can also be dissected, providing an advantage in exposing the mandibular nerve, from the gasserian ganglion to the infratemporal fossa [82–84]. Drilling the base of the pterygoid, in combination with the removal of the anterior wall of the sphenoid sinus, allows for exposure of the lateral wall of the sphenoid sinus as well as its lateral recess. Based on the pathological scenario, the approach can be combined with a classic transsellar approach, extended laterally.

The anatomy of the area is particularly complex, making surgery especially challenging. Specific technological tools assist the surgeon. When dealing with the cavernous sinus, venous bleeding must be controlled with hemostatic agents, and the use of the Doppler allows for the correct detection of the internal carotid artery. Neuromonitoring is mandatory to minimize morbidity related to cranial nerves, especially the III, IV, and VI, in cavernous sinus dissection.

Lower transpterygoid approach: The dissection of the caudal portion of the pterygoid process gives access to the upper portion of the parapharyngeal space. This is an inverted pyramid shaped volume [77], whose boundaries are the prevertebral space posteriorly, infratemporal fossa and submandibular fossa anterolaterally, the parotid space along with nodal levels IB and IIA posterolaterally, and the nasopharynx and oropharynx medially [85]. It can be divided into upper, middle, and lower portions based on horizontal axial planes passing through the lower border of the lateral pterygoid lamina and the mandibular angles [85, 86]. Furthermore, it can also be segmented in prestyloid and retrostyloid compartments, by a plane passing through the styloid process [77]. The area of major clinical interest which can be targeted endoscopically is the upper parapharyngeal space, further divided in medial and lateral, with the corresponding surgical corridors. The medial approach provides control of the eustachian tube and associated muscles, while the lateral one allows a correct visibility of the internal carotid artery and jugular foramen, and associated neurovascular structures.




▶ **Fig. 11** Case of recurrent nasopharyngeal carcinoma. The primary lesion underwent radio-chemotherapy. The patient developed recurrent disease on the right Rosenmuller's fossa (arrows in image **a**-**b** and star in image **c**). The patient underwent endoscopic nasopharyngectomy type 3, with the sectioning of the Eustachian tube (white arrow in **d**). MS – Maxillary sinus; NS – Nasal Septum; SpS – Sphenoid Sinus.

Typical lesions involving the area are nasopharyngeal cancers. Undifferentiated nasopharyngeal carcinomas are usually addressed endoscopically in case of recurrence after (chemo)-radiotherapy. For other histologies, like salivary gland cancers and melanomas, endoscopic surgery may represent the primary treatment option, followed or not by adjuvant treatment [87–91].

The nasopharyngeal endoscopic resection (NER) is the transnasal approach designed to resect nasopharyngeal lesion involving the upper parapharyngeal space [87]. The main surgical challenge is to avoid injuries to the parapharyngeal tract of the internal carotid artery, while achieving free surgical margins. When performing NER, it is crucial to recognize bony landmarks, understand fascial planes, adopt the correct endoscopic perspective, and utilize preoperative imaging and navigation tools to locate and preserve the internal carotid artery. The procedure starts with the exposure and lateralization of the content of the pterygopalatine fossa via a transmaxillary approach. The medial pterygoid lamina is removed to expose the medial pterygoid muscle, tensor veli palatini and levator veli palatini muscles, and eustachian tube. The internal carotid artery lies behind the tube, pointed by the lateral pterygoid lamina. The vidian nerve represents a useful landmark for the foramen lacerum. The dissection of tissues medial and inferior to it, is safe from injuries of the carotid, except for cases of prominent kinking.

In extended cases, the trans-nasal route is combined to other approaches (i. e. transoral, transorbital, transcervical, and transpetrosal), integrated in a multiportal surgical strategy [92] (▶ **Fig. 11**).

## Conflict of interest

The authors declare that they have no conflict of interest.

## References


[1] Lund VJ et al. *European position paper on endoscopic management of tumours of the nose, paranasal sinuses and skull base*. Rhinol Suppl 2010; 22: 1–143

[2] Patel CR et al. *Skull Base Anatomy*. Otolaryngol Clin North Am 2016; 49:9–20

[3] Verillaud B et al. *Endoscopic endonasal skull base surgery*. Eur Ann Otorhinolaryngol Head Neck Dis 2012; 129: 190–6

[4] Kassam AB et al. *Expanded endonasal approach: fully endoscopic, completely transnasal approach to the middle third of the clivus, petrous bone, middle cranial fossa, and infratemporal fossa*. Neurosurg Focus 2005; 19: E6

[5] Kassam A et al. *Expanded endonasal approach: the rostrocaudal axis. Part I. Crista galli to the sella turcica*. Neurosurg Focus 2005; 19: E3

[6] Kassam A et al. *Expanded endonasal approach: the rostrocaudal axis. Part II*. Posterior clinoids to the foramen magnum. Neurosurg Focus 2005; 19: E4

[7] Schwartz TH et al. *Endoscopic cranial base surgery: classification of operative approaches*. Neurosurgery 2008; 62: 991–1002

[8] Schwartz TH, Morgenstern PF, Anand VK. *Lessons learned in the evolution of endoscopic skull base surgery*. J Neurosurg 2019; 130: 337–346

[9] Kasemsiri P et al. *Advantages and limitations of endoscopic endonasal approaches to the skull base*. World Neurosurg 2014; 82: S12–21

[10] Snyderman CH et al. *Endoscopic skull base surgery: principles of endonasal oncological surgery*. J Surg Oncol 2008; 97: 658–64

[11] Kassam AB et al. *Endoscopic endonasal skull base surgery: analysis of complications in the authors' initial 800 patients*. J Neurosurg 2011; 114: 1544–68

[12] Cavallo LM, Solari D, Cappabianca P. *Multiportal Approach to the Skull Base: One Key, Multiple Gates*. World Neurosurg 2015; 84: 630–1

[13] Turri-Zanoni M et al. *Multiportal combined transnasal transoral transpharyngeal endoscopic approach for selected skull base cancers*. Head Neck 2016; 38: E2440–e2445

[14] Sindwani R, Woodard TD, Recinos PF. *Building a Successful Endoscopic Skull Base and Pituitary Surgery Practice*. Otolaryngol Clin North Am 2016; 49: 1–8

[15] Cervantes SS, Lal D. *Crista galli mucocele: endoscopic marsupialization via frontoethmoid approach*. Int Forum Allergy Rhinol 2014; 4: 598–602

[16] Pinheiro-Neto CD et al. *Endoscopic endonasal surgery for nasal dermoids*. Otolaryngol Clin North Am 2011; 44: 981–7. ix

[17] Selleck AM et al. *Management of Frontal Sinus Tumors*. Otolaryngol Clin North Am 2016; 49: 1051–65

[18] Shidanshid M et al. *Endoscopic resection of a mucocele of the crista galli*. Ear Nose Throat J 2015; 94: E23–5

[19] Ma J et al. *Endoscopic transnasal repair of cerebrospinal fluid leaks with and without an encephalocele in pediatric patients: from infants to children*. Childs Nerv Syst 2015; 31: 1493–8

[20] Nyquist GG et al. *Endoscopic endonasal repair of anterior skull base non-traumatic cerebrospinal fluid leaks, meningoceles, and encephaloceles*. J Neurosurg 2010; 113: 961–6

[21] Re M et al. *Endonasal endoscopic approach for intracranial nasal dermoid sinus cysts in children*. Int J Pediatr Otorhinolaryngol 2012; 76: 1217–22

[22] Karligkiotis A et al. *Endoscopic endonasal orbital transposition to expand the frontal sinus approaches*. Am J Rhinol Allergy 2015; 29: 449–56

[23] Belotti F et al. Transfrontal Approach, in Endoscopic Transnasal Anatomy of the Skull Base and Adjacent Areas, P. Nicolai, et al., Editors.2020: Thieme; 95

[24] Greenfield JP et al. *Endoscopic endonasal transethmoidal transcribriform transfovea ethmoidalis approach to the anterior cranial fossa and skull base*. Neurosurgery 2010; 66: 883–92. discussion 892

[25] Verillaud B et al. *Transcribriform and transplanum endoscopic approach for skull-base tumors*. Eur Ann Otorhinolaryngol Head Neck Dis 2013; 130: 233–6

[26] Koutourousiou M et al. *Endoscopic endonasal surgery for olfactory groove meningiomas: outcomes and limitations in 50 patients*. Neurosurg Focus 2014; 37: E8

[27] Fernandez-Miranda JC et al. *Expanded endonasal approach for olfactory groove meningioma*. Acta Neurochir (Wien) 2009; 151: 287–8. author reply 289-90

[28] de Divitiis E et al. *Endoscopic transnasal resection of anterior cranial fossa meningiomas*. Neurosurg Focus 2008; 25: E8

[29] Gardner PA et al. *Endoscopic endonasal resection of anterior cranial base meningiomas*. Neurosurgery 2008; 63: 36–52. discussion 52-4

[30] Blake DM et al. *Endoscopic endonasal resection of sinonasal and anterior skull base schwannomas*. J Clin Neurosci 2014; 21: 1419–23

[31] Liu JK, Eloy JA. *Expanded endoscopic endonasal transcribriform approach for resection of anterior skull base olfactory schwannoma*. J Neurosurg 2012; 32: E3

[32] Vaz-Guimaraes F et al. *Endoscopic endonasal surgery for epidermoid and dermoid cysts: a 10-year experience*. J Neurosurg 2018; 1–11

[33] Castelnuovo P et al. *Endoscopic endonasal surgery for malignancies of the anterior cranial base*. World Neurosurg 2014; 82: S22–31

[34] Krischek B et al. *From craniofacial resection to endonasal endoscopic removal of malignant tumors of the anterior skull base*. World Neurosurg 2014; 82: S59–65

[35] Lund V, Howard DJ, Wei WI. *Endoscopic resection of malignant tumors of the nose and sinuses*. Am J Rhinol 2007; 21: 89–94

[36] Lund VJ, Wei WI. *Endoscopic surgery for malignant sinonasal tumours: an eighteen year experience*. Rhinology 2015; 53: 204–11

[37] Moya-Plana A et al. *Development of minimally invasive surgery for sinonasal malignancy*. Eur Ann Otorhinolaryngol Head Neck Dis 2016; 133: 405–411

[38] Nicolai P et al. *Endoscopic surgery for malignant tumors of the sinonasal tract and adjacent skull base: a 10-year experience*. Am J Rhinol 2008; 22: 308–16

[39] Nicolai P, Castelnuovo P, Bolzoni Villaret A. *Endoscopic resection of sinonasal malignancies*. Curr Oncol Rep 2011; 13: 138–44

[40] Villaret AB et al. *Endoscopic transnasal craniectomy in the management of selected sinonasal malignancies*. Am J Rhinol Allergy 2010; 24: 60–5

[41] Hanna E et al. *Endoscopic resection of sinonasal cancers with and without craniotomy: oncologic results*. Arch Otolaryngol Head Neck Surg 2009; 135: 1219–24

[42] Meccariello G et al. *Endoscopic nasal versus open approach for the management of sinonasal adenocarcinoma: A pooled-analysis of 1826 patients*. Head Neck 2016; 38: E2267–74

[43] Liu JK et al. *Transbasal versus endoscopic endonasal versus combined approaches for olfactory groove meningiomas: importance of approach selection*. Neurosurg Focus 2018; 44: E8

[44] Ottenhausen M et al. *Decision-making algorithm for minimally invasive approaches to anterior skull base meningiomas*. Neurosurg Focus 2018; 44: E7

[45] Banu MA et al. *Endoscope-assisted endonasal versus supraorbital keyhole resection of olfactory groove meningiomas: comparison and combination of 2 minimally invasive approaches*. J Neurosurg 2016; 124: 605–20

[46] Tajudeen BA et al. *Smell preservation following endoscopic unilateral resection of esthesioneuroblastoma: a multi-institutional experience*. Int Forum Allergy Rhinol 2016; 6: 1047–1050

[47] Ferrari M et al. Transcribriform Approach, in Endoscopic Transnasal Anatomy of the Skull Base and Adjacent Areas, P. Nicolai, et al., Editors.2020: 108–132

[48] Mattavelli D et al. *Three-Layer Reconstruction with Iliotibial Tract After Endoscopic Resection of Sinonasal Tumors*. World Neurosurg 2017; 101: 486–492

[49] Mattavelli D et al. *Complications and donor site morbidity of 3-layer reconstruction with iliotibial tract of the anterior skull base: Retrospective analysis of 186 patients*. Head Neck 2018; 40: 63–69

[50] Cappabianca P et al. *Endoscopic endonasal transsphenoidal surgery: procedure, endoscopic equipment and instrumentation*. Childs Nerv.Syst. 2004; 20: 796–801

[51] Conrad J et al. *Binostril versus mononostril approaches in endoscopic transsphenoidal pituitary surgery: clinical evaluation and cadaver study*. J Neurosurg 2016; 125: 334–45

[52] Reisch R, Briner HR, Hickmann AK. *How I do it: the mononostril endonasal transethmoidal-paraseptal approach*. Acta Neurochir (Wien) 2017; 159: 453–457

[53] Hadad G et al. *A novel reconstructive technique after endoscopic expanded endonasal approaches: vascular pedicle nasoseptal flap*. Laryngoscope 2006; 116: 1882–6

[54] Oldfield EH, Vortmeyer AO. *Development of a histological pseudocapsule and its use as a surgical capsule in the excision of pituitary tumors*. J Neurosurg 2006; 104: 7–19

[55] Knosp E et al. *Pituitary adenomas with invasion of the cavernous sinus space: a magnetic resonance imaging classification compared with surgical findings*. Neurosurgery 1993; 33: 610–7. discussion 617-8

[56] Nagata Y et al. *Removal of the Medial Wall of the Cavernous Sinus for Functional Pituitary Adenomas: A Technical Report and Pathologic Significance*. World Neurosurg 2019; 126: 53–58

[57] Micko A et al. *Challenging Knosp high-grade pituitary adenomas*. J Neurosurg 2019; 1–8

[58] Cohen-Cohen S et al. *The medial wall of the cavernous sinus. Part 2: Selective medial wall resection in 50 pituitary adenoma patients*. J Neurosurg 2018; 1–10

[59] Woodworth GF et al. *Surgical outcomes using a medial-to-lateral endonasal endoscopic approach to pituitary adenomas invading the cavernous sinus*. J Neurosurg 2014; 120: 1086–94

[60] Silveira-Bertazzo G et al. *Expanded endoscopic endonasal approach for extending suprasellar and third ventricular lesions*. Acta Neurochir (Wien) 2020; 162: 2403–2408

[61] Zwagerman NT et al. *Endoscopic transnasal skull base surgery: pushing the boundaries*. J Neurooncol 2016; 130: 319–330

[62] Schreiber A et al. *Modular Endoscopic Medial Maxillectomies: Quantitative Analysis of Surgical Exposure in a Preclinical Setting*. World Neurosurg 2017; 100: 44–55

[63] Zhou B et al. *Intranasal endoscopic prelacrimal recess approach to maxillary sinus*. Chin Med J (Engl) 2013; 126: 1276–80

[64] Morrissey DK, Wormald PJ, Psaltis AJ. *Prelacrimal approach to the maxillary sinus*. Int Forum Allergy Rhinol 2016; 6: 214–8

[65] Suzuki M et al. *Modified transnasal endoscopic medial maxillectomy through prelacrimal duct approach*. Laryngoscope 2017; 127: 2205–2209

[66] Guo T et al. *Endoscopic endonasal surgery for pterygopalatine fossa schwannoma via prelacrimal recess-maxillary sinus*. B-ENT 2014; 10: 81–6

[67] He S et al. *A combination of modified transnasal endoscopic maxillectomy via transnasal prelacrimal recess approach with or without radiotherapy for selected sinonasal malignancies*. Eur Arch Otorhinolaryngol 2015; 272: 2933–8

[68] Bertazzoni G et al. *Contemporary management of juvenile angiofibroma*. Curr Opin Otolaryngol Head Neck Surg 2019; 27: 47–53

[69] Langdon C et al. *Expanded endoscopic endonasal surgery for advanced stage juvenile angiofibromas: a retrospective multi-center study*. Rhinology 2016; 54: 239–46

[70] Karligkiotis A et al. *Role of endoscopic surgery in the management of sinonasal and skull base schwannomas*. Head Neck 2016; 38: E2074–82

[71] Shi J et al. *Neuroendoscopic Resection of Trigeminal Schwannoma in the Pterygopalatine/Infratemporal Fossa via the Transnasal Perpendicular Plate Palatine Bone or Transnasal Maxillary Sinus Approach*. World Neurosurg 2018; 120: e1011–e1016

[72] Yang L et al. *Endoscopic endonasal approach for trigeminal schwannomas: our experience of 39 patients in 10 years*. Eur Arch Otorhinolaryngol 2018; 275: 735–741

[73] Zhou B et al. *The intranasal endoscopic removal of schwannoma of the pterygopalatine and infratemporal fossae via the prelacrimal recess approach*. J Neurosurg 2016; 124: 1068–73

[74] Battaglia P et al. *Endoscopic transnasal approaches to pterygopalatine fossa tumors*. Head Neck 2016; 38: E214–20

[75] Elhadi AM et al. *Infraorbital nerve: a surgically relevant landmark for the pterygopalatine fossa, cavernous sinus, and anterolateral skull base in endoscopic transmaxillary approaches*. J Neurosurg 2016; 125: 1460–1468

[76] Nicolai P et al. Transpterygomaxillary Approach, in Endoscopic Transnasal Anatomy of the Skull Base and Adjacent Areas, P. Nicolai, et al., Editors.2020: 271–288

[77] Stambuk HE, Patel SG. *Imaging of the parapharyngeal space*. Otolaryngol Clin North Am 2008; 41: 77–101. vi

[78] Dallan I et al. *Endoscopic transnasal anatomy of the infratemporal fossa and upper parapharyngeal regions: correlations with traditional perspectives and surgical implications*. Minim Invasive Neurosurg 2010; 53: 261–9

[79] Ohue S et al. *Preauricular transzygomatic anterior infratemporal fossa approach for tumors in or around infratemporal fossa lesions*. Neurosurg Rev 2012; 35: 583–92. discussion 592

[80] Hosseini SM et al. *Endonasal transpterygoid approach to the infratemporal fossa: correlation of endoscopic and multiplanar CT anatomy*. Head Neck 2012; 34: 313–20

[81] Schreiber A et al. Infratemporal Fossa Approach, in Endoscopic Transnasal Anatomy of the Skull Base and Adjacent Areas, P. Nicolai, et al., Editors. 2020: 289–306

[82] Schmidt RF et al. *Surgical nuances for the endoscopic endonasal transpterygoid approach to lateral sphenoid sinus encephaloceles*. Neurosurgical Focus FOC 2012; 32: E5

[83] R. V. et al. The Suprapetrous (Meckel's Cave) Approach, in Endoscopic Transnasal Anatomy of the Skull Base and Adjacent Areas, P. Nicolai, et al., Editors. 2020: Thieme; 374–375

[84] Rampinelli V et al. The Suprapetrous (Meckel's Cave) Approach, in Endoscopic Transnasal Anatomy of the Skull Base and Adjacent Areas, P. Nicolai, et al., Editors.2020: Thieme; 374–375

[85] Ferrari M et al. *Surgical anatomy of the parapharyngeal space: Multiperspective, quantification-based study*. Head Neck 2019; 41: 642–656

[86] Prasad SC et al. *Lateral skull base approaches in the management of benign parapharyngeal space tumors*. Auris Nasus Larynx 2015; 42: 189–98

[87] Castelnuovo P et al. *Endoscopic endonasal nasopharyngectomy in selected cancers*. Otolaryngol Head Neck Surg 2013; 149: 424–30

[88] Liu J et al. *Salvage endoscopic nasopharyngectomy for local recurrent or residual nasopharyngeal carcinoma: a 10-year experience*. Int J Clin Oncol 2017; 22: 834–842

[89] Vlantis AC et al. *Endoscopic nasopharyngectomy in recurrent nasopharyngeal carcinoma: a case series, literature review, and pooled analysis*. Int Forum Allergy Rhinol 2017; 7: 425–432

[90] Ong YK et al. *Endoscopic nasopharyngectomy and its role in managing locally recurrent nasopharyngeal carcinoma*. Otolaryngol Clin North Am 2011; 44: 1141–54

[91] Lepera D et al. *Endoscopic transnasal resection of Eustachian-tube dermoid in a new-born infant*. Auris Nasus Larynx 2015; 42: 235–40

[92] Schreiber A et al. Medial Parapharyngeal Approach, in Endoscopic Transnasal Anatomy of the Skull Base and Adjacent Areas, P. Nicolai, et al., Editors.2020: 409–428