Endoscopic Endonasal Approach for Craniopharyngiomas

Jörg Baldauf, MD[a], Werner Hosemann, MD[b], Henry W.S. Schroeder, MD[a,*]

KEYWORDS

• Endoscopic endonasal approach • Craniopharyngiomas • Retrochiasmatic tumor

KEY POINTS

- The endoscopic endonasal approach for the management of craniopharyngiomas has increasingly been used as an alternative to microsurgical transsphenoidal or transcranial approaches.
- This approach is a major step forward in the treatment of these difficult lesions because of improved resection rates and better visual outcome.
- Especially in retrochiasmatic tumors, the endonasal approach provides better access to the lesion and reduces the degree of manipulations of the optic apparatus.
- The panoramic view offered by endoscopy and the use of angulated optics allows the removal of lesions extending far into the third ventricle avoiding microsurgical brain splitting.

A video of the endoscopic endonasal resection of an intraventricular craniopharyngeoma accompanies this article at http://www.neurosurgery.theclinics.com/

INTRODUCTION

Craniopharyngiomas (CPs) represent one of the most challenging tumor entities in neurosurgery. Because of its critical vicinity to important neurovascular structures, the surgery is demanding and requires a thorough understanding of the anatomy of the suprasellar region.

CPs are benign epithelial tumors of the sellar region originating from remnants of Rathke's cleft. They are classified by the World Health Organization as grade I neoplasms.[1] The papillary form is almost exclusively found in the adult population and the adamantinomatous subtype mainly occurs in children.[2,3] There is a bimodal age distribution of the incidence of CPs with a higher amplitude in childhood. However, the prognosis of these tumors in particular is a matter of growth pattern. The extent of the tumor in relation to the optic chiasm, pituitary gland and stalk, hypothalamus, carotid artery, and anterior cerebral artery complex as well as the location of the tumor with respect to the sella and diaphragm, is important for surgical planning. In addition to the tumor size and the multilobulated characteristics with solid and cystic components, it is of significant interest whether the lesion does extend into the third ventricle or not and its relation to it. To solve the problem of choosing the right surgical strategy for individual cases, a variety of topographic and clinical classifications of CPs have been transferred into surgical practice parallel to

Disclosure: H.W.S. Schroeder is consultant to Karl Storz GmbH & Co KG (Tuttlingen, Germany).

[a] Department of Neurosurgery, Ernst Moritz Arndt University, Sauerbruchstrasse, Greifswald 17475, Germany; [b] Department of Otorhinolaryngology, Ernst Moritz Arndt University, Walter-Rathenau-Strasse 43-45, Greifswald 17475, Germany

* Corresponding author.

E-mail address: henry.schroeder@uni-greifswald.de

Neurosurg Clin N Am ■ (2015) ■–■

http://dx.doi.org/10.1016/j.nec.2015.03.013

1042-3680/15/$ – see front matter © 2015 Elsevier Inc. All rights reserved.

technological progress of instrumentation and equipment.[2,4–7]

Albert E. Halsted has been credited with the first successful transsphenoidal resection of a CP performed in 1909.[8] The transsphenoidal approach for tumors of the sellar region is strongly related to Harvey Cushing and Oskar Hirsch.[9] In 1909, Cushing described his first surgery through the transsphenoidal route for partial removal of the pituitary gland in a patient with acromegaly.[10] A detailed historical review concerning the endonasal approach for CPs written by Gardner and colleagues[11] mentioned that Cushing abandoned the approach for CPs for safety reasons given by technological and visualization limitations. In contrast, Hirsch developed and kept to the endonasal transsphenoidal approach and reported his first small series of 12 patients treated for tumors of the pituitary gland in 1911 at the third international laryngo-rhinological congress in Berlin.[12] Ten of the patients improved in clinical outcome and 2 died. The latter were subjected to autopsy. In one, a large tumor of the pituitary gland was found that mainly extended into the intracranial space and third ventricle. Hirsch made 2 important statements about his experience regarding the transsphenoidal approach. First, an improvement of clinical symptoms can be expected if the tumor is located exclusively inside the sella and reveals cystic components. Second, if a tumor is mainly growing intracranially, the endonasal approach and all other extracranial methods will not succeed. Fortunately, the introduction of the operating microscope opened a new door to neurosurgery in general, as well as to the transsphenoidal endonasal route particularly. Hardy stressed the importance of the microsurgical approach for pituitary adenomas and CPs in 1971 and mentioned that "the intrasellar subdiaphragmatic type of CP can be totally removed transphenoidally."[13] Laws improved the microsurgical technique for CPs and expressly underlined that if "the sella turcica is enlarged, transsphenoidal microsurgery can be the procedure of choice, even when significant intracranial extension is present."[14,15]

The stepwise technological progress extended the transsphenoidal access, initially described by Weiss,[16] to reach the suprasellar/supradiaphragmatic space. However, transcranial approaches to CPs with intraventricular growth have also been used via pterional, transcortical, interhemispheric, transcallosal, and transforaminal routes.[2]

The microsurgical–endonasal resection of sellar tumors was successfully complemented by the use of an endoscope by Apuzzo and colleagues[17] in 1977 after Guiot had already introduced the endoscope to transsphenoidal surgery more than a decade earlier.[18] Two decades later, Carrau and Jho reported their first series of purely endoscopic endonasal removal of pituitary adenomas.[19,20] The continuous advancement of the endoscope, in addition to the development of specific instruments and sophisticated endoscopic studies of the parasellar and anterior skull base anatomy allowed the extension of the spectrum of indications for the technique. This initial work was spearheaded by "The original Pittsburgh group" with Carrau, Kassam and co-workers as well as the Naples group with Cappabianca and De Divitiis, and also the Bologna group with Frank and Pasquini, who promoted the endoscopic extended endonasal approach in the early years of the 21st century.[21–24] Nowadays, the endoscopic approach is widely accepted and is used regularly. However, there is a long learning curve and cadaver studies are recommended. Additionally, close cooperation between an ENT-head and neck surgeon and neurosurgeon is necessary. Based on their extraordinary experience, Kassam and colleagues[24] specified a V-level scale of complexity of endoscopic endonasal skull base procedures that provides a useful guide. According to their scale, the endoscopic endonasal approach to CPs is a level IV category referring to the fact that intradural surgery is usually required. Several studies have demonstrated already excellent results for CP patients.[25–30] Compared with the transcranial microscopic approach, the endoscopic approach promises a higher rate of gross total resection (GTR) and improved visual outcome because there is less manipulation of the optic apparatus, especially in retrochiasmatic lesions.[31]

INDICATIONS AND LIMITATIONS FOR ENDOSCOPIC EXTENDED ENDONASAL APPROACH

Patients with CPs can present with a great variety of symptoms including headache, visual symptoms, hormonal disorders such diabetes insipidus and hypopituitarism, mental and memory disturbances, gait difficulties, and hypothalamic disturbances such as the Fröhlich's syndrome (adiposogenital dystrophy). The typical symptoms of increased intracranial pressure are commonly related to an associated hydrocephalus owing to tumor extension into the third ventricle.

All symptomatic CPs are an indication for surgery. Asymptomatic lesions can be followed with MRI. However, growing lesions should be treated before they become symptomatic.[32] If the patient presents with acute hydrocephalus owing to obstruction of the foramina of Monro by a cystic

component of the tumor, an initial transcranial transventricular endoscopic cyst fenestration can be performed before the endonasal tumor resection to release the increased intracranial pressure.

The goal of surgery for CPs is GTR or near total resection, if feasible. However, tumor removal has to be restricted to subtotal resection or even partial resection when the risk of neurovascular damage is expected to be high to avoid unacceptable postoperative morbidity. The surgical approach depends on the individual growth pattern of the tumor. Important essentials for the endoscopic extended endonasal approach are listed in **Table 1** and limitations are presented in **Box 1** with respect to the recent literature.[6,25,27,30] Categories A through G try to display an increase of the necessary surgical expertise according to certain pathologic conditions. Each surgical case must be assessed individually for the endoscopic extended endonasal approach or should be alternatively considered for a primary or second stage transcranial approach. Type IV CP isolated to the third ventricle and/or optic recess according Kassam and colleagues[6] is stressed to be not feasible by extended endonasal approach. In our opinion, the endonasal approach is especially useful and superior to any transcranial approach when the lesion is retrochiasmatic with a prefixed chiasm. Compared with the transcranial approach, manipulation of the optic apparatus is reduced, as is the risk of visual deterioration. The success of tumor removal depends on the consistency and characteristics of the lesion (solid, cystic, or multilobular) as well as the invasion of the hypothalamic area.

Table 1
Categories of surgical expertise of endoscopic extended endonasal approach for craniopharyngiomas regarding tumor location/extension according to recent literature

Category	Tumor Location/Extension
A	Intrasellar + infradiaphragmatic
B	Intrasuprasellar + infradiaphragmatic
C	Suprasellar + infradiaphragmatic; preinfundibular
D	Supradiaphragmatic; preinfundibular, transinfundibuar
E	+ Ventricle floor compression
F	+ Ventricular invasion
G	Pure intraventricular

Data from Refs.[6,25,27,30]

Box 1
Limitations and unfavorable factors of the endoscopic extended endonasal approach

1. Hypoplastic sphenoid sinus
2. Narrow sellar floor/reduced intercarotid artery distance
3. Combined prechiasmatic and retrochiasmatic tumor extension
4. Significant lateral tumor extension
5. Predominantly solid component in large tumors
6. Type IV lesions according to Kassam[6]

The latter has to be thoroughly assessed in all kind of CPs involving the third ventricle and represents the main reason for preventing a GTR.

SURGICAL MANAGEMENT

Preoperative Planning

Taking a case history and performing a neurologic examination are the first steps in the patient evaluation. Additionally, endocrinologic and visual assessment (visual acuity and visual field) is mandatory before and after surgery. An early consultation with an ENT is advisable to define details of the individual surgical strategy. We strongly recommend neuropsychological testing for adults and children before surgery, if the condition of the patient allows, because behavioral or cognitive problems can already be present before intervention or might occur after tumor resection.[33,34] Furthermore, the body mass index and eating behavior are of interest because of the possibility of postoperative obesity and hyperphagia owing to hypothalamic damage.[35]

Sophisticated preoperative imaging is of utmost importance and includes CT and MRI. CT reveals calcifications within solid nodules and rim or capsule of cystic parts. Thin layer bone window CT demonstrates the bony anatomy of the paranasal sinuses, nasal cavity, clivus, and anterior skull base. It discloses nasal septum deviations, conchal abnormalities, and provides an exact map of the intrasphenoid septations, which are important for anatomic orientation. MRI demonstrates tumor extension in every plane including differentiation in solid and cystic components of the tumor. It provides the basis to evaluate the surgical corridor as mentioned in **Table 1** and **Box 1**. Neurovascular conflicts such as distortions of the optic chiasm or branches of the Circle of Willis

are well visualized on T2 sequences. These authors agree with others that a special meaning is related to the axial and coronal fluid-attenuated inversion recovery or T2 sequences regarding hypothalamic invasion by the tumor.[32] Our illustrative case presents typical MRI features (Fig. 1).

Depending on the imaging findings, an approach is selected. The decision to approach the lesion transcranially or endonasally depends on several factors. One of the most important considerations is the position of the chiasm in relation to the tumor. If the tumor is located retrochiasmatic, pushing the chiasm anteriorly (prefixed chiasm), the endonasal approach provides better access to the lesion avoiding unnecessary manipulations of the chiasm. This is especially true in smaller tumors, which only elevate the floor of the third ventricle but are not located intraventricularly. In these lesions, the lamina terminalis approach should not be chosen. If the tumor is located anteriorly to the chiasm causing a postfixed chiasm like in tuberculum sellae meningiomas, the lesion can be approached transcranially or endonasally. However, in most CPs, there is a prefixed chiasm. If the tumor has significant lateral extension (>1 cm lateral to the carotids), it might be impossible to remove these parts totally through the nose when they are stuck to the

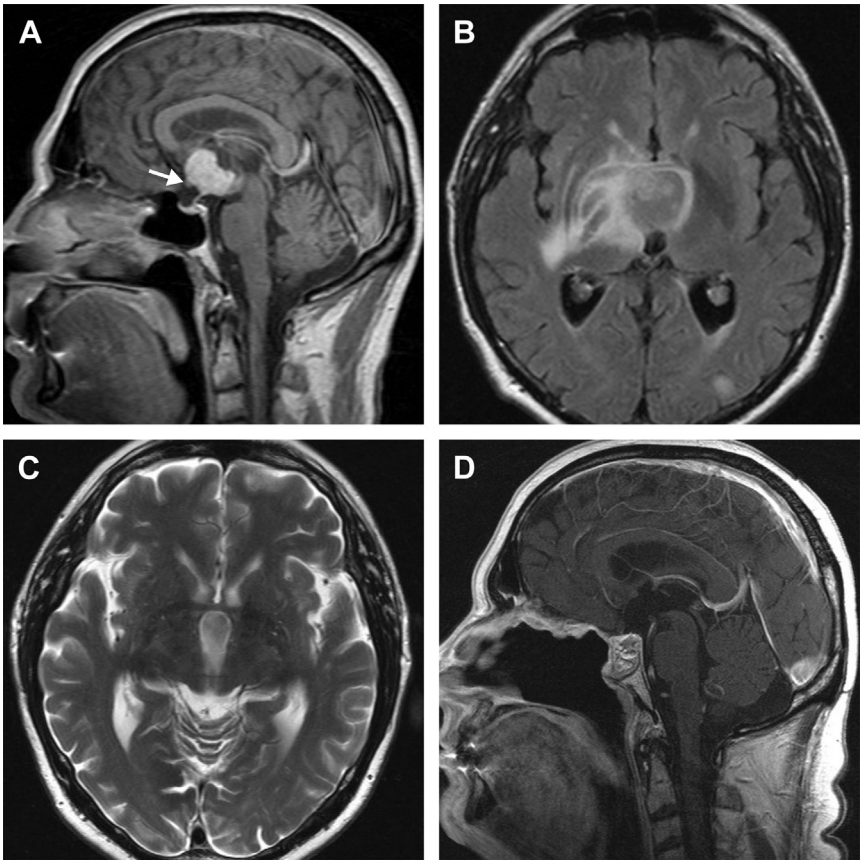

Fig. 1. This 61-year-old man presented with a 6-month history of progressive mental deterioration including decrease of short-term memory. Ten days before admission, he developed a disturbance of consciousness, disorientation, and bladder dysfunction. Endocrinologic evaluation demonstrated panhypopituitarism and diabetes insipidus. A typical Addisonian crisis was observed. MRI revealed a suprasellar contrast enhancing tumor extending into the third ventricle with solid components (*A*). The optic chiasm was displaced anteriorly (*arrow*). Pituitary gland and sella seemed to be normal. Hypothalamic invasion of the lesion was suspected because of the perifocal edema on T2 and fluid-attenuated inversion recovery images with lateral extension into the basal ganglia on the right side (*B*). Gross total resection was performed, including section of the pituitary stalk, which was already infiltrated and destroyed by the tumor. The sphenoid and intradural phases of the extended endonasal approach is shown in Figs. 2 and 3. Postoperatively, the patient was very confused, but recovered soon regarding conscious level and cognitive function. Surprisingly, body weight remained stable. Hormonal substitution is required. There is no recurrence of the tumor on MRI 2 years after surgery (*C, D*). The edema has resolved completely (*C*). Image (*D*) also demonstrates covering of the skull base defect by the nasoseptal flap.

surrounding structures. Tumors with large lateral extension should undergo removal via craniotomy. However, tumor extension into the third ventricle, even when they fill the entire ventricle, can be removed endonasally, provided there is communication with the suprasellar space and no ventricular wall invasion. The axis of the approach is ideal to get even the tumor parts in the posterior third ventricle.

Usually, a transsellar–transtuberculum–transplanum approach is sufficient to remove a CP. In tumors with retroclival tumor extension, an addition transclival approach has to be added. In giant tumors with extension in all directions, a combined endonasal–transcranial approach may be necessary. In the rare instance of a purely intrasellar craniopharyngeoma, a simple transsellar approach is sufficient. The approach, steps, and goal of the surgery should be discussed between rhinosurgeon and neurosurgeon at least the day before the surgery.

Perioperative Care and Patient Positioning

After induction of general anesthesia, the endotracheal tube is positioned and fixed in the left corner of the mouth. The nasal surgical part may be characterized by mucosal bleeding. Therefore, a throat pack is inserted to the oral cavity to protect the oropharynx from accumulation of blood and irrigation solution during the surgical procedure. Xylometazoline 0.1% or epinephrine (1:1000) is applied to the nasal mucosa before surgery with the aid of cotton pads. Preoperative antibiotics (cefuroxime 1.5 g) are administered intravenously. The application is repeated when the surgery lasts longer than 6 hours. If a major cerebrospinal fluid (CSF) leak is expected, a lumbar drain is inserted, but is kept closed until the end of the surgery. Postoperative CSF diversion diminishes tension on the skull base reconstruction avoiding CSF leakage.

Perioperatively, 100 mg hydrocortisone is given intravenously within the first hour of surgery followed by 100 mg hydrocortisone administered over the first 24 hours. Oral medication is then continued. The dose depends on the clinical situation of the patient.

The position of the patient is supine and the back elevated to 30° to reduce the venous pressure within the cavernous sinus. The neck is tilted gently to the left and the head slightly extended and turned toward the surgeon fixed to a Mayfield clamp. If required, the navigational image guidance is set up and patient registration is performed using CT and MRI data.

Beside the preparation of nose and nasal cavity with iodine solution, the periumbilical region is disinfected in case a fat graft is needed. Then the patient is draped and the ceiling-mounted boom arm that houses all videoendoscopic equipment needed during surgery is positioned. The 2 right-handed surgeons stand on the right side of the patient. The operating nurse stands on the opposite side to allow easy change of the surgical instruments. The ventilator and the anesthesiologist are positioned on the left side of the patient at the foot level.

SURGICAL APPROACH

General Aspects

Our endoscopic endonasal surgery is a 2-surgeon, 3- or 4-handed technique as proposed by Kassam and colleagues.[6] This technique enables 1 surgeon to work bimanually in the depth while the other surgeon is moving the endoscope like a "mobile" endoscope holder (Video 1). The advantage is the flexible mobility of the endoscope with respect to the operating field, which is somehow missing with a fixed holding device. Sometimes, a third instrument is used by the second surgeon helping in the dissection, but usually he irrigates frequently to clean the lens and the surgical field. We use 18-cm-long rigid rod–lens Hopkins endoscopes with a diameter of 4 mm (Karl Storz GmbH & Co KG, Tuttlingen, Germany). For very narrow nostrils or nasal cavities, 2.7-mm scopes are available; however, they are rarely required. Most of the surgery is performed under view of a 0° endoscope. However, the 30° and 45° endoscopes are also frequently used to work around a corner and to visualize intraventricular tumor extensions. In our opinion, a prerequisite for extended endonasal surgery for CPs is a high-definition video camera. High definition provides a brilliant image that allows easily the differentiation of the various tissues like, for example, the tumor, hypothalamus, and gliotic plane, which can be difficult with a standard progressive addition lens or NTSC (National Television System Committee) camera.[36] Usually, the ENT–head and neck surgeon starts the procedure. However, the neurosurgeon should be able to perform this part of the surgery as well. This is important in a case of emergency when the ENT is not available.

In our opinion, the endoscopic extended endonasal approach can be divided in different steps, which have been described and mentioned by others.[6,32,37]

The Nasal Phase

The initial nasal phase of the approach is characterized by binostril endoscopic inspection of the nasal cavity to visualize the nasal anatomy. The choana as the main landmark, the turbinates,

and, if possible, the sphenoid ostium are identified on both sides. Then, the lower and middle turbinates are lateralized to create some working space. To protect the mucosa, we place cotton pads soaked in with xylometazoline on the turbinates. The main working nostril is on the right side because the endoscope is placed here together with another instrument or suction device. We try to avoid resection of the right middle turbinate, but excision may be necessary if lateral dislocation does not provide enough space. Then, a nasoseptal flap is created and stored in the nasopharynx. The size of the flap depends on the size of the skull base defect expected for the approach. Usually, we harvest the flap on the right side, but if there are major bony spurs or other unsuitable anatomic conditions, we elevate the flap on the left side. It is important to preserve at least 1 cm of the septal mucosa near the skull base so as to not endanger the sense of olfaction. It is also important to preserve the vascular pedicle (nasoseptal artery) of the flap at the site of the posterior septal artery. After having stored the flap in the nasopharynx, the posterior bony parts of the septum are removed and a reverse flap of the contralateral mucosa is created to cover the anterior parts of the ipsilateral denuded septum. This flap is fixed with 2 sutures to the anterior cartilaginous septum.[38]

The Sphenoid Phase

The sphenoid phase starts using both nostrils for bimanual manipulation. The rostrum of the sphenoid sinus is removed with the aid of a high-speed drill. The sphenoid sinus is opened wide in all directions. Great care has to be taken to preserve the vascular pedicle of the flap when opening the sphenoid sinus on the side of the flap. On the contralateral side, the mucosal branches of the sphenopalatine artery (posterior septal artery) should be coagulated to avoid postoperative hemorrhage. A posterior ethmoidectomy is performed until the tuberculum sellae and the planum sphenoidale are exposed sufficiently. The mucosa of the sphenoid sinus is removed and the intrasphenoidal bony septa are drilled flat to provide a good bed for the nasoseptal flap.[6,39] The created space must guarantee an optimal dissection within the sphenoid cavity avoiding collisions of the instruments during surgical maneuvers. When the sphenoid sinus is well pneumatized, important anatomic landmarks can easily be identified, such as the optic canals, carotid protuberances of the clival and cavernous carotid artery, clivus, and lateral and medial opticocarotid recesses. When the sphenoid sinus is not well-pneumatized, neuronavigation is helpful to stay oriented during the necessary bone removal.

The next step is the drilling of the skull base. We routinely create a wide opening in the skull base to provide ample room for dissection. The bony sellar floor, the tuberculum sellae, and the posterior planum are removed from carotid to carotid and optic nerve to optic nerve, respectively. The drilling technique is characterized by eggshell thinning of the bone with diamond drills and gentle elevation of the remaining layer with a plate dissector (**Fig. 2**A–C). Continuous irrigation is required while drilling because it keeps the vision clear and avoids heat injury to the underlying neurovascular structures. The medial aspects of the optic canals and the cavernous carotids are unroofed partially. If the tumor has significant retroclival extension, the upper clivus is drilled as well. Significant venous bleeding is rarely encountered during the transsellar–transplanum–transtuberculum approach. If it occurs, it can easily be managed by application of FloSeal hemostatic sealant (Baxter Healthcare Corporation, Hayward, CA) especially if the cavernous or intercavernous sinus are involved.

The Intradural Phase

The intradural step starts with horizontal dural incisions below and above the superior intercavernous sinus to facilitate coagulation of the sinus (see **Fig. 2**D–F). Alternatively, the sinus can be occluded with titanium clips.[37] After transection of the superior intercavernous sinus, the upper dural incision is extended in a V-shaped fashion anteriorly in the direction of the optic nerves. The anteriorly based dural flap can be excised or simply coagulated if it is falling back and obscuring the access to the suprasellar region. Thereafter, the diaphragma sellae is cut until the pituitary stalk is reached. Early identification of the pituitary stalk is a major advantage of the endonasal approach. Before the arachnoid is opened, the superior hypophyseal arteries have to be identified. It is of utmost importance to preserve the vessels because they represent the major blood supply to the chiasm and stalk (**Fig. 3**A, B). Then, the arachnoid is cut to expose the tumor.

The relation of the tumor to the stalk is explored. When a patient presents with panhypopituitarism and the stalk is infiltrated (especially transinfundibular type II lesions according to Kassam and colleagues),[6] we do not hesitate to sacrifice it. If it is still functioning, all efforts are taken to preserve the stalk. We agree that, in type II transinfundibular CPs, a high stalk section is recommended to achieve a GTR.[32,40]

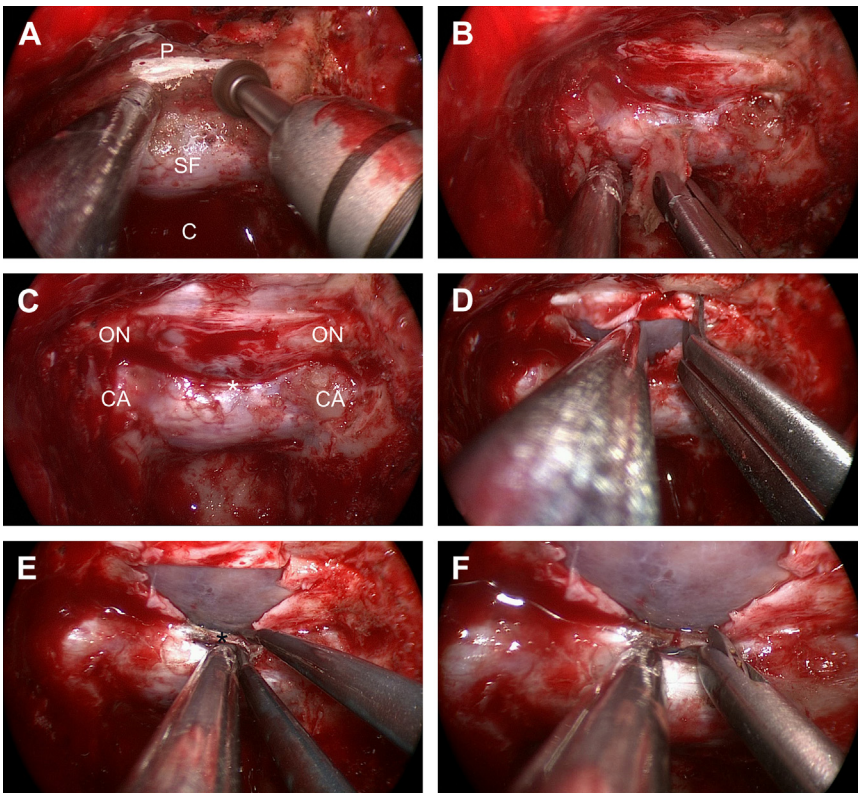

Fig. 2. Sphenoid phase. (*A*) Eggshell drilling of the sella floor (SF) and planum sphenoidale (P) within in the sphenoid cavity. (*B*) Thin bone layers are removed. (*C*) Panoramic view on the exposed dura after complete bone removal. Location of the optic nerve (ON), carotid artery (CA), and superior intercavernous sinus (SIS [*asterisk*]) are labeled. (*D*) Dura opening of the suprasellar space. (*E*) Coagulation of the SIS. (*F*) Section of the SIS.

The concept of CP surgery is characterized by initial debulking of the tumor and identification of the interface between the tumor and adjacent anatomic structures and especially the hypothalamus, which is frequently only a paper thin membrane. After a sharp incision of the tumor capsule, cystic parts of the lesion are evacuated by suction, and solid tumor tissue is removed with the aid of grasping forceps, curettes, or ultrasonic aspirator (see **Fig. 3**C–F). If the tumor is very calcified, all techniques are insufficient and the tumor has to be removed in a time-consuming piecemeal fashion with cutting instruments. After debulking, the dissection plane between hypothalamus and tumor is identified. The dissection is performed around the tumor, before it is removed. It is ill-advised to simply pull on the tumor, because it can be adherent to the basilar artery, perforators, and hypothalamus. Cystic components of the tumor located within the third ventricle are frequently not adherent to the ventricular wall, and can be removed easily. Sometimes, the CSF pressure pushes the cystic part spontaneously out of the ventricle. When the tumor is collapsed, an extracapsular dissection along the gliotic cleavage plane is done bimanually by gentle traction–countertraction using 2 grasping forceps. The most difficult decision to be made during the resection is how radical of a dissection to undertake. No general recommendation can be given. It is a very individual decision that is made while resecting the lesion. We usually attempt a GTR of the lesion. However, when we cannot identify a dissection plane between the craniopharyngeoma and the hypothalamus, we perform a near total resection, leaving a thin layer of tumor on the hypothalamus. Usually, there is a good arachnoid dissection plane between the tumor and the neurovascular structures of the interpeduncular fossa. Sharp dissection is preferred in this area. If the tumor is not coming down spontaneously, 30° or even 45° endoscopes have to be used to dissect the tumor from the upper third ventricle. The tumor is expected to be adherent to the hypothalamus and columns of the fornix. Consequently, visual control while working around the corner is mandatory at this point of surgery to avoid forniceal damage or venous bleeding caused by traction injury.

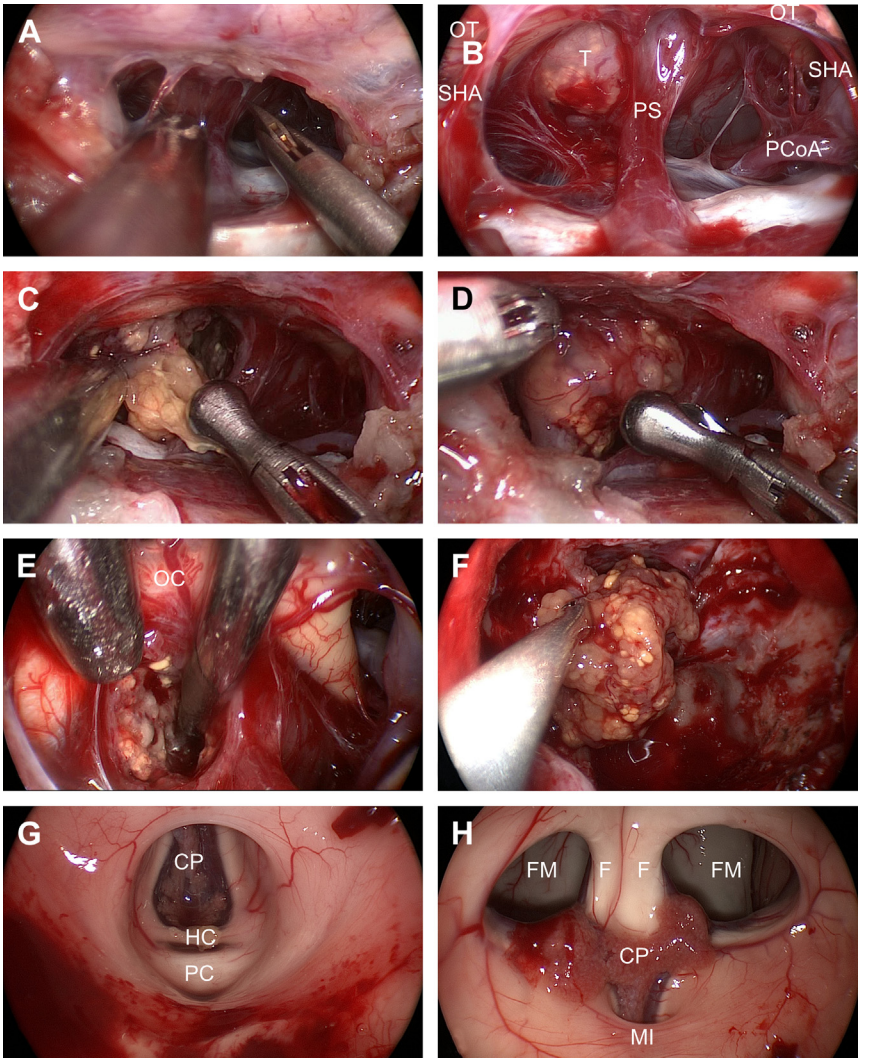

Fig. 3. Intradural phase. (*A*) Supradiaphragmatic sharp dissection of arachnoid membranes. (*B*) The supradiaphragmatic area is exposed. Pituitary stalk (PS), posterior communicating artery (PCoA), superior hypophyseal artery (SHA), optic tract (OT), and tumor (T) are visualized. (*C*) Debulking of the tumor. (*D*) Bimanual extracapsular dissection with grasping and dissection forceps. The PS is lateralized to the left. (*E*) Switching to a 30° endoscope enables safe retrochiasmatic tumor debulking (optic chiasm [OC]). (*F*) A large piece of tumor is mobilized from the third ventricle to the sphenoid cavity. (*G*) Final inspection of the dorsal part of the third ventricle after complete tumor removal (choroid plexus [CP], habenular commissure [HC], posterior commissure [PC]). (*H*) Inspection of the anterior part of the third ventricle with the 45° endoscope (choroid plexus [CP], fornix [F], foramen of Monro [FM], and massa intermedia [MI]).

After tumor resection, the surgical field is irrigated thoroughly to remove blood and tumor debris. The third ventricle is inspected using a 45° endoscope (see Fig. 3G, H).

Closure

Endonasal approaches for craniopharyngiomas usually result in a major CSF leak, particularly if the tumor extends into the third ventricle. Therefore, a sophisticated skull base closure technique is mandatory to avoid a postoperative CSF leak.[31] We usually avoid any foreign material and prefer fat, fibrin glue, and the nasoseptal flap (Fig. 4). We put a piece of fat in the skull base defect so that it cannot fall intradurally into the resection cavity of the tumor. A larger part of the fat graft remains extradural between the planum

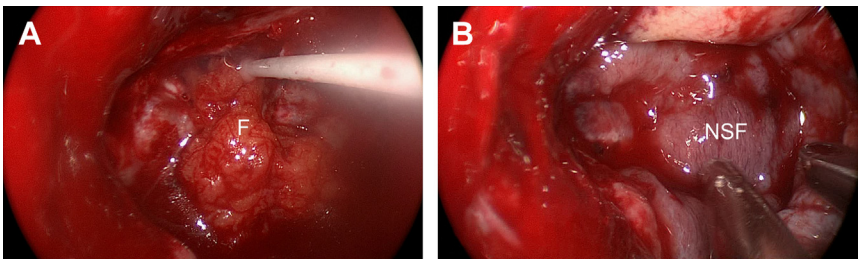

Fig. 4. Closure of the skull base defect. (*A*) Insertion of a fat graft (F) on dural level with intradural extension. Fibrin glue application on boarder area. (*B*) Covering the bony margins with a pedicled, vascularized nasoseptal flap (NSF).

and the sella. If the clivus is indented deeply, a fat graft is placed for a better fit of the nasoseptal flap. The fat is fixed with a little bit fibrin glue. Thereafter, the nasoseptal flap is mobilized from the nasopharynx and carefully positioned over the defect avoiding any foldings in the flap. The flap should be at least 5 to 8 mm larger than the defect in all directions because it will shrink a bit. Utmost care has to be taken to place the correct (periosteal) surface of the flap on the exposed skull base. Additionally, fibrin glue is applied around the edge of the flap. The flap is then covered with Surgicel (oxidized cellulose; Ethicon, Inc, Somerville, NJ) and gel foam to protect the flap. Finally, nasal tamponades are placed to support the flap. They remain in place for 3 to 5 days. The lumbar drainage is opened immediately after surgery to secure CSF diversion and prevent increases in intracranial pressure. It remains open for 5 days continuously at the level of the external auditory canal. In rare cases presenting preoperatively with hydrocephalus, a CSF leak may persist and ultimately require a ventriculoperitoneal shunt to stop the leakage.

COMPLICATIONS AND MANAGEMENT

Complications may occur intraoperatively or postoperatively. Intraoperative complications include injury to neurovascular structures, which may lead to major hemorrhage, brain infarction, and cranial nerve palsies. Nerve palsies occur fortunately only rarely, and are mostly transient affecting the III and IV nerves.[26,41] Utmost care has to be taken when the tumor is adherent to the basilar artery and perforators arising from the basilar tip. Rupture of the perforators may lead to coma and death. Dissection of an adherent lesion to the chiasm may result in decline of visual acuity and visual field cut. Preservation of the superior hypophyseal arteries is essential in preserving vision.

The most frequent postoperative complication seen after endoscopic extended endonasal approach for CPs is a CSF leak. It has been reported to occur in 3.8% to 69%.[25,26] Cavallo and colleagues[30] observed that the risk of CSF leakage increases in patients with third ventricle involvement. We agree that placing a lumbar drain to reduce CSF pressure over the skull base reconstruction is advisable in cases with wide opening of the third ventricle. Because of routine application of the vascularized pedicled nasoseptal flap, the CSF leak rate after extended endonasal approach with intraarachnoidal dissection has decreased dramatically.[39,42] The prolonged postoperative discomfort with crusting and discharge resulting from harvesting of the nasoseptal flap can be reduced with the reverse mucosal flap covering the donor site. Headache and reduced olfaction leading to a reduced quality of life have been reported as well.[43]

Other complications of the endoscopic extended endonasal approach in CPs are meningitis and hydrocephalus.[25,26,28–30,41] Complications, causes, and their management are presented in **Table 2**. In terms of worsening of pituitary function diabetes insipidus is mostly seen. Up to 46% permanent diabetes insipidus was observed by Koutourousiou and colleagues.[28] The study also demonstrated that 78% of the children were affected and only 32% of the adults.

Similar to diabetes insipidus, hypopituitarism often exists preoperatively or may deteriorate after surgery. Newly diagnosed panhypopituitarism after endoscopic intervention has been reported in up to 67% of patients postoperatively.[44]

Consequences of hypothalamic injury represent an important factor to patients' quality of life. An increase in body mass index of more than 9% underlines the problem of hyperphagia.[26] Mental disorders after extended endonasal approach for CP may be discovered as well.[26,41]

OUTCOME

The rate of GTR of endoscopic extended endonasal approach reaches around 70% in several

Table 2
Complications after endoscopic extended endonasal approach for craniopharyngiomas

Complication	Cause	Management
CSF leakage	Insufficient closure Hydrocephalus	Lumbar drainage; reexploration and repair Shunting[a]
Hydrocephalus	Preexisting hydrocephalus; hemorrhage	Shunting
Hemorrhage	Tumor adherent to neurovascular structures	Hematoma evacuation External drainage in case of hydrocephalus
Subdural hematoma[30]	Loss of CSF, pneumocephalus	Hematoma evacuation Subdural drainage
Cranial nerve palsy	Manipulation, dissection	Wait and see
Intraoperative vascular damage[24,25]	Injury owing to dissection/vascular attachment	Irrigation, diathermy, application of hemostatic agents, compression
Infection of fat graft[26]	Suspected pick up of bacteria during fat passage through a contaminated nasal corridor	Reoperation, endonasal washout, antibiotics
Meningitis	Bacterial infection	Antibiotics
Diabetes insipidus/ hypopituitarism/ SIADH/ hypernatremia	Manipulations of the stalk/ hypothalamus; stalk sacrifice; damage to pituitary or hypothalamic blood supply, vasospasm	Medical treatment
Visual decline	Manipulation; vascular Hydrocephalus	Wait and see Shunting
Hyperphagia, weight gain, obesity	Hypothalamic injury	Dietary restriction
Memory disturbance	Hypothalamic injury	Wait and see
Psychoorganic syndrome	Hypothalamic injury	Medical treatment
Rhinologic sequelae (crusting/synechiae/ sinusitis/hyposmia–anosmia)	Inappropriate resection of nasal mucosa; laceration of functional narrow passes and ostia	Rhinologic aftercare (douching, ointments, surgery for reventilation)

Abbreviations: CSF, cerebrospinal fluid; SIADH, syndrome of inappropriate antidiuretic hormone.
[a] Shunt treatment is also indicated for recurrent CSF leakage.
Data from Refs.[24–26,30]

studies.[25,29,30,45] The extent of tumor resection is related to tumor location, consistency, and mainly adherence to neurovascular structures in particular to the hypothalamus. In the cohort reported by Koutourousiou and colleagues,[28] the overall GTR rate was only 37.5%. However, they stated that "GTR was not considered safe and was therefore not attempted in every patient." It is, therefore, necessary to recognize that subtotal resection in combination with adjuvant radiotherapy may lower the risk of perioperative morbidity in a certain number of patients.[46] A systematic review by Komotar and colleagues[31] revealed an advantage of the endoscopic extended endonasal approach and transsphenoidal microscopic approach compared with open transcranial approaches to achieve GTR in CPs. Additionally, improvement of vision after extended endonasal approach (56%) is significantly better in contrast with transcranial approaches (33%) and tends to be superior to microscopic transsphenoidal approach (44%). The same study demonstrated that deterioration of vision is less pronounced in extended endonasal approach than in the other approaches.

Outcome regarding degree of tumor resection and visual improvement in studies with at least 20 patients is documented in **Table 3**.

Table 3
Outcome in studies on extended endonasal approach greater than 20 patients regarding GTR/NTR/vision improvement

Author, Year	No Patients/Surgeries	GTR/NTR	Vision Improvement
Koutourousiou et al,[28] 2013	64	24 (37.5)/22 (34.4)	38 (86.4)
Leng et al,[26] 2012	26	18 (69)/2 (7.9)	20 (77)
Kalinin et al,[41] 2013	56	39 (69.4)/—	32 (57.4)
Cavallo et al,[30] 2014	103	71 (68.9)/—	59 (74.7)

GTR/NTR/vision improvement presented as number of patients (%).
Abbreviations: GTR, gross tumor resection; NTR, near total resection.
Data from Refs.[26,28,30,41]

SUMMARY

The introduction of the endoscopic endonasal extended approach is a major step forward in the management of craniopharyngeomas. It has improved the resection rate and the visual outcome. Especially in retrochiasmatic lesions pushing the chiasm anteriorly (prefixed chiasm), the endonasal approach provides a better access to the lesion and reduces the degree of manipulations of the optic apparatus. The panoramic view offered by endoscopy and the use of angulated optics allows the removal of lesions extending far into the third ventricle avoiding microsurgical brain splitting such as translamina terminalis or transcallosal approaches. Of course, there is a significant learning curve in this demanding surgery, requiring intensive training before performing this intervention.

ACKNOWLEDGMENTS

The authors thank M. Matthes, MSc, for his help in preparing the illustrations.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at http://dx.doi.org/10.1016/j.nec.2015.03.013.

REFERENCES

1. Louis DN, Ohgaki H, Wiestler OD, et al. The 2007 WHO classification of tumours of the central nervous system. Acta Neuropathol 2007;114(2):97–109.
2. Adamson TE, Wiestler OD, Kleihues P, et al. Correlation of clinical and pathological features in surgically treated craniopharyngiomas. J Neurosurg 1990; 73(1):12–7.
3. Larkin SJ, Ansorge O. Pathology and pathogenesis of craniopharyngiomas. Pituitary 2013;16(1):9–17.
4. Fukushima T, Hirakawa K, Kimura M, et al. Intraventricular craniopharyngioma: its characteristics in magnetic resonance imaging and successful total removal. Surg Neurol 1990;33(1):22–7.
5. Pascual JM, Gonzalez-Llanos F, Barrios L, et al. Intraventricular craniopharyngiomas: topographical classification and surgical approach selection based on an extensive overview. Acta Neurochir (Wien) 2004;146(8):785–802.
6. Kassam AB, Gardner PA, Snyderman CH, et al. Expanded endonasal approach, a fully endoscopic transnasal approach for the resection of midline suprasellar craniopharyngiomas: a new classification based on the infundibulum. J Neurosurg 2008;108(4):715–28.
7. Hoffman HJ, De SM, Humphreys RP, et al. Aggressive surgical management of craniopharyngiomas in children. J Neurosurg 1992;76(1):47–52.
8. Halstead AE. Remarks on operative treatment of tumors of the hypophysis. Trans Am Surg Assoc 1910; 28:73–93.
9. Hirsch O. Ueber endonasale Operationsmethoden bei Hypophysis-Tumoren mit Bericht über 12 operierte Fälle. Berl Klin Wschr 1911;48:1933–5.
10. Cushing H III. Partial hypophysectomy for acromegaly: with remarks on the function of the hypophysis. Ann Surg 1909;50(6):1002–17.
11. Gardner PA, Prevedello DM, Kassam AB, et al. The evolution of the endonasal approach for craniopharyngiomas. J Neurosurg 2008;108(5):1043–7.
12. Liu JK, Cohen-Gadol AA, Laws ER Jr, et al. Harvey Cushing and Oskar Hirsch: early forefathers of modern transsphenoidal surgery. J Neurosurg 2005; 103(6):1096–104.
13. Hardy J. Transsphenoidal hypophysectomy. 1971. J Neurosurg 2007;107(2):458–71.
14. Laws ER Jr. Transsphenoidal removal of craniopharyngioma. Pediatr Neurosurg 1994;21(Suppl):157–63.
15. Laws ER Jr. Transsphenoidal microsurgery in the management of craniopharyngioma. J Neurosurg 1980;52(5):661–6.
16. Weiss MH. The transnasal transsphenoidal approach. In: Apuzzo MJ, editor. Surgery of the third

ventricle. Baltimore (MD): Williams & Wilkins; 1987. p. 476–94.
17. Apuzzo ML, Heifetz MD, Weiss MH, et al. Neurosurgical endoscopy using the side-viewing telescope. J Neurosurg 1977;46(3):398–400.
18. Guiot G, Thibaut B, Bourreau M. Extirpation of hypophyseal adenomas by trans-septal and trans-sphenoidal approaches. Ann Otolaryngol 1959;76:1017–31 [in French].
19. Carrau RL, Jho HD, Ko Y. Transnasal-transsphenoidal endoscopic surgery of the pituitary gland. Laryngoscope 1996;106(7):914–8.
20. Jho HD, Carrau RL. Endoscopic endonasal transsphenoidal surgery: experience with 50 patients. J Neurosurg 1997;87(1):44–51.
21. Cappabianca P, Cavallo LM, Esposito F, et al. Extended endoscopic endonasal approach to the midline skull base: the evolving role of transsphenoidal surgery. Adv Tech Stand Neurosurg 2008;33:151–99.
22. De Divitiis E, Cavallo LM, Cappabianca P, et al. Extended endoscopic endonasal transsphenoidal approach for the removal of suprasellar tumors: Part 2. Neurosurgery 2007;60(1):46–58.
23. Frank G, Pasquini E, Mazzatenta D. Extended transsphenoidal approach. J Neurosurg 2001;95(5):917–8.
24. Kassam AB, Prevedello DM, Carrau RL, et al. Endoscopic endonasal skull base surgery: analysis of complications in the authors' initial 800 patients. J Neurosurg 2011;114(6):1544–68.
25. Gardner PA, Kassam AB, Snyderman CH, et al. Outcomes following endoscopic, expanded endonasal resection of suprasellar craniopharyngiomas: a case series. J Neurosurg 2008;109(1):6–16.
26. Leng LZ, Greenfield JP, Souweidane MM, et al. Endoscopic, endonasal resection of craniopharyngiomas: analysis of outcome including extent of resection, cerebrospinal fluid leak, return to preoperative productivity, and body mass index. Neurosurgery 2012;70(1):110–23.
27. Cavallo LM, Solari D, Esposito F, et al. The endoscopic endonasal approach for the management of craniopharyngiomas involving the third ventricle. Neurosurg Rev 2013;36(1):27–37.
28. Koutourousiou M, Gardner PA, Fernandez-Miranda JC, et al. Endoscopic endonasal surgery for craniopharyngiomas: surgical outcome in 64 patients. J Neurosurg 2013;119(5):1194–207.
29. Bosnjak R, Benedicic M, Vittori A. Early outcome in endoscopic extended endonasal approach for removal of supradiaphragmatic craniopharyngiomas: a case series and a comprehensive review. Radiol Oncol 2013;47(3):266–79.
30. Cavallo LM, Frank G, Cappabianca P, et al. The endoscopic endonasal approach for the management of craniopharyngiomas: a series of 103 patients. J Neurosurg 2014;121(1):100–13.
31. Komotar RJ, Starke RM, Raper DM, et al. Endoscopic endonasal compared with microscopic transsphenoidal and open transcranial resection of craniopharyngiomas. World Neurosurg 2012;77(2):329–41.
32. Conger AR, Lucas J, Zada G, et al. Endoscopic extended transsphenoidal resection of craniopharyngiomas: nuances of neurosurgical technique. Neurosurg Focus 2014;37(4):E10.
33. Ondruch A, Maryniak A, Kropiwnicki T, et al. Cognitive and social functioning in children and adolescents after the removal of craniopharyngioma. Childs Nerv Syst 2011;27(3):391–7.
34. Bellhouse J, Holland A, Pickard J. Psychiatric, cognitive and behavioural outcomes following craniopharyngioma and pituitary adenoma surgery. Br J Neurosurg 2003;17(4):319–26.
35. Roth CL. Hypothalamic obesity in patients with craniopharyngioma: profound changes of several weight regulatory circuits. Front Endocrinol (Lausanne) 2011;2:49.
36. Schroeder HW, Nehlsen M. Value of high-definition imaging in neuroendoscopy. Neurosurg Rev 2009;32(3):303–8.
37. Cappabianca P, Frank G, Pasquini E, et al. Extended endoscopic endonasal transsphenoidal approaches to the suprasellar region, planum sphenoidale & clivus. In: De Divitiis E, Cappabianca P, editors. Endoscopic endonasal transsphenoidal surgery. Wien (Austria); New York: Springer; 2003. p. 176–82.
38. Kasemsiri P, Carrau RL, Otto BA, et al. Reconstruction of the pedicled nasoseptal flap donor site with a contralateral reverse rotation flap: technical modifications and outcomes. Laryngoscope 2013;123(11):2601–4.
39. Hadad G, Bassagasteguy L, Carrau RL, et al. A novel reconstructive technique after endoscopic expanded endonasal approaches: vascular pedicle nasoseptal flap. Laryngoscope 2006;116(10):1882–6.
40. Liu JK, Christiano LD, Patel SK, et al. Surgical nuances for removal of retrochiasmatic craniopharyngioma via the endoscopic endonasal extended transsphenoidal transplanum transtuberculum approach. Neurosurg Focus 2011;30(4):E14.
41. Kalinin PL, Fomichev DV, Kutin MA, et al. Endoscopic endonasal anterior extended transsphenoidal approach in craniopharyngioma surgery. Zh Vopr Neirokhir Im N N Burdenko 2013;77(3):13–20 [in Russian].
42. Kassam AB, Thomas A, Carrau RL, et al. Endoscopic reconstruction of the cranial base using a pedicled nasoseptal flap. Neurosurgery 2008;63(1 Suppl 1):ONS44–52.
43. Georgalas C, Badloe R, van Furth W, et al. Quality of life in extended endonasal approaches for skull base tumours. Rhinology 2012;50(3):255–61.

44. Jane JA Jr, Kiehna E, Payne SC, et al. Early outcomes of endoscopic transsphenoidal surgery for adult craniopharyngiomas. Neurosurg Focus 2010; 28(4):E9.
45. Frank G, Pasquini E, Doglietto F, et al. The endoscopic extended transsphenoidal approach for craniopharyngiomas. Neurosurgery 2006;59(1 Suppl 1):ONS75–83.
46. Schoenfeld A, Pekmezci M, Barnes MJ, et al. The superiority of conservative resection and adjuvant radiation for craniopharyngiomas. J Neurooncol 2012;108(1):133–9.