



# Clivus and Upper Cervical Spine

# 8

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## Abbreviations

CCJ	Cranio-cervical junction
CN	Cranial nerve
CSF	Cerebrospinal fluid
CT	Computed tomography
EEA	Endoscopic endonasal approach
EMG	Electromyographic
GTR	Gross total resection
HD	High definition
ICA	Internal carotid artery
MEP	Motor evoked potential
MRI	Magnetic resonance imaging
NSF	Nasoseptal flap
PPF	Pterygopalatine fossa
PPG	Pterygopalatine ganglion
PSA	Posterior septal artery
SSEP	Somatosensory evoked potential

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## 8.1 Introduction

Surgical access to the clival and occipitocervical region has long been fraught with numerous complications owing to a deep location, a complex anatomy, and difficulty in obtaining a watertight closure. To gain access to lesions in those deep locations, extensive skull base exposures, including the “far-lateral” suboccipital craniotomy as described by Heros et al. and the transoral approach, refined by Menezes [1], and subfrontal transbasal, transmaxillary, transmandibular, and preauricular infratemporal approaches, were for many years the only available options.

In the past two decades, the refinement and popularization of endoscopic endonasal techniques in neurosurgery have allowed an increasing number of lesions and pathologies located in the clivus and high cervical spine to be treated through a more limited exposure and straighter line of sight and surgical corridor. Jho and Carrau pioneered the endoscopic transsphenoidal surgery for pituitary lesions [2] but are also credited for the description of the first endoscopic endonasal resection of a clival chordoma [3]. In 2002, Frempong-Boaudu first described the use of endoscopic assistance in transoral surgeries [4]. Kassam et al. subsequently described the first case of odontoidectomy performed through an endoscopic endonasal approach in 2005 [5].

A major stride in endoscopic endonasal surgery has been the description of the Hadad-Bassagasteguy flap, or nasoseptal flap (NSF), in 2006 [6]. It has since become the first choice for vascularized mucosal coverage of large skull base defects, both for its ease of harvest and the large surface it can cover, and most importantly the reduction in the cerebrospinal fluid leak rate. Other options for vascularized reconstruction have since been described, and a better understanding has been gained of what is required in terms of closure technique depending on the anatomical location and clinical scenario.

In this chapter, we discuss the more recent advances in endoscopic endonasal, microscopic transcranial, and endoscopic-assisted transcranial approaches as applied to lesions in the lower clival and high cervical region. We will

focus on the surgical treatment of clival and craniocervical junction chordomas, as these are the archetypal lesions encountered in this location.

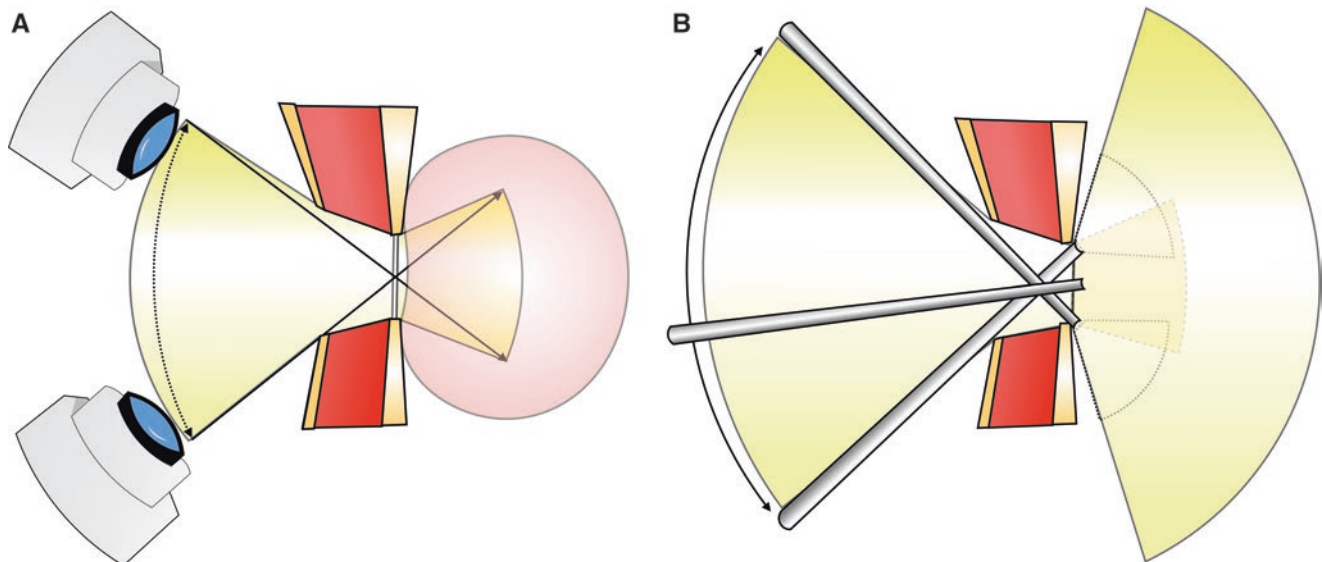
## 8.2 Rationale

Numerous surgical approaches to the clivus and craniocervical junction (CCJ) region have been described, and obviously, no one approach is applicable and most appropriate for all lesions in this location. However, many of the pathologies frequently encountered in the clivus and the CCJ typically affect the ventromedial compartment, making the endonasal corridor the more direct surgical route, thus avoiding extensive manipulation of neurological and vascular structures. This fact may in part explain the generally more favorable results in terms of cranial nerve preservation obtained in endoscopic endonasal series when compared to series reporting on tumor resection performed through a posterolateral corridor [7].

As for high cervical lesions, the rationale behind the development of endoscopic endonasal techniques was the relatively high “cost” of transoral approaches to the ventral CCJ in terms of morbidity. In fact, in many cases, a palatal incision that would have been required in a transoral exposure can be avoided through an endonasal approach. Additionally, the mucosal incision is located higher when an endonasal route is utilized which potentially limits the infectious risk, quickens extubation, and allows earlier reintroduction of oral feeding. There is also reduced tongue swelling in the postoperative period since this approach does not require tongue retraction [8].

However, endonasal exposures of CCJ pathology often require resection of soft tissue and endonasal structures rather than manipulation or transposition as compared to classic transcranial open approaches. It thus involves additional morbidity with at least temporary reduction in quality of life. Additionally, the risk of CSF leak, even though reduced with modern reconstruction techniques, remains a significant issue especially in cases with an expected large dural defect, reoperations, and previously irradiated patients. Hence, the classic transcranial posterolateral approaches, including the far-lateral approach, retain some key advantages when dealing with the CCJ. In addition to the lower risk of CSF leak, posterolateral approaches do not involve resection of parapharyngeal muscles or the Eustachian tube, nor manipulation of the soft palate, allowing for complications such as velopharyngeal insufficiency and chronic serous otitis to be reduced or avoided altogether.

On the other hand, the deep central location of this anatomical region, deep to the soft tissues of the nuchal muscles, makes it difficult to reach through a small incision and keyhole approach similar to the subfrontal, mini-pterional or suboccipital keyhole approaches. However, it does not mean that the keyhole concept together with the endoscope cannot be utilized to reach via the classic far lateral corridor the ventral aspect of the craniocervical junction. Doing so, the “keyhole” is not located on the skin and convexity but is located deeper, at the level of the condylar region (Fig. 8.1a, b). Through a keyhole that is drilled or already made available by the tumor at the level of the condyle, the utilization of the endoscope is paramount to expose and resect parts of the lesion located higher at the levels of the lower- and mid-clivus, the prevertebral space, and infiltrating the odontoid, lateral



**Fig. 8.1** (a, b). Keyhole concept in posterolateral approaches to the CCJ. (a). Exposure afforded by the microscope through a “keyhole” craniotomy. Soft tissues can impose significant limitations to the area

visualized with blind spots under the edges of the craniotomy. (b). Increased viewing angle and illumination with the use of the endoscope inside the “keyhole,” which is at the level of the craniotomy

masses of C1, and body of C2. This allows for equivalent tumor resection or neurological decompression through more limited exposures, which in turn is thought to be associated with less morbidity and shorter hospital stays.

Lastly, in some cases, the best approach is to combine endoscopic endonasal and transcranial techniques so as to benefit from the advantage of both and reduce the overall morbidity. In essence, modern skull base surgeons must utilize multimodal (microscopic and endoscopic) and multiportal (endonasal and transcranial) techniques to optimize clinical outcome.

### 8.3 Potential Pathologies

The most frequent lesions that neurosurgeons must manage in the lower clival and high cervical region are chordomas and degenerative diseases (rheumatoid arthritis and basilar impression). However, the differential diagnosis is quite varied (Table 8.1), and the clinician must be able to differentiate these preoperatively as the surgical management is often different from one lesion to the other.

#### Chordomas

Skull base chordomas are lesions arising from notochordal remnants in the clival region. They usually present as well-delineated multilobulated lesions of the midline

cranial base, typically hyperintense on T2 and contrast enhancing. Notwithstanding their “benign” histology, these lesions tend to grow on a follow-up, causing osteolysis of the cancellous bone in which they are embedded, and, eventually, break through the cortical bone and invade the surrounding structures, such as the dura and the intradural compartment. They also have the tendency to infiltrate and grow along soft tissue planes, including between dural leaflets which makes gross total resection a true challenge. Clinically, clival chordomas most frequently present with a 6th nerve palsy, while lower cranial nerve dysfunction is also common at presentation at the level of the CCJ [9].

Although the literature has been somewhat conflicting in the past, there is now extensive evidence showing that gross total resection improves overall survival and progression-free survival in skull base chordomas [10, 11]. Another important prognostic factor to take into consideration is the quality of the resection at first attempt. In fact, in most surgical series, GTR appears harder to achieve in residual and recurrent disease than during the first surgical attempt. Every effort should hence be made to maximize resection during the first surgery. Chordomas of the CCJ have a poorer prognosis than those located elsewhere in the skull base or the cervical spine [9]. This finding may be related to the deep location and invasiveness of CCJ chordomas into the surrounding soft tissues and the resulting lower rate of GTR and higher recurrence risk.

**Table 8.1** Differential diagnosis of clival and CCJ pathologies

Congenital
Malformations of the occipital bone (platybasia, condylar hypoplasia, etc.)
Basilar invagination
Irregular segmentation
Inflammatory and degenerative
Rheumatoid arthritis <sup>a</sup>
Basilar impression <sup>a</sup>
Infectious (osteomyelitis, Grisel’s syndrome)
Tumor
Chordoma <sup>a</sup>
Chondrosarcoma
Meningioma
Glomus tumor
Schwannoma of the lower cranial nerves
Other bone tumors (myeloma, osteoma, etc.)
Secondary lesions
Vascular
Vertebrobasilar aneurysms
Trauma
Chronic instability
Ventral compression

<sup>a</sup>Most frequent lesions

#### Chondrosarcomas

Chondrosarcomas are rare at the CCJ but it bears mentioning that their surgical treatment is somewhat more complex. In fact, they are often located more laterally and their consistency is more fibrous and they are frequently calcified. Most authors agree that, owing to the indolent nature of this tumor, GTR is not as important as for chordomas and priority must be given to the functional outcome. In some cases of complete resection, close follow-up may be considered. However, upfront adjuvant proton beam therapy is probably safer in case of incomplete resections. These management decisions must also take into account the grade of the chondrosarcoma.

#### Degenerative Diseases and Malformations of the CCJ

Although a number of degenerative diseases of the CCJ can be treated medically, with cervical traction or standalone posterior decompression, a number of indications for anterior decompression, including odontoidectomy, are still well

established. Menezes et al. have published and advocated an algorithm-based management for these lesions in which the first line of treatment is generally reduction with cervical traction [12]. Also, in rheumatoid arthritis with anterior inflammatory pannus, there is usually significant improvement of the anterior compression after a posterior occipito-cervical fusion.

#### 8.4 Patient Selection: Indications/Contraindications

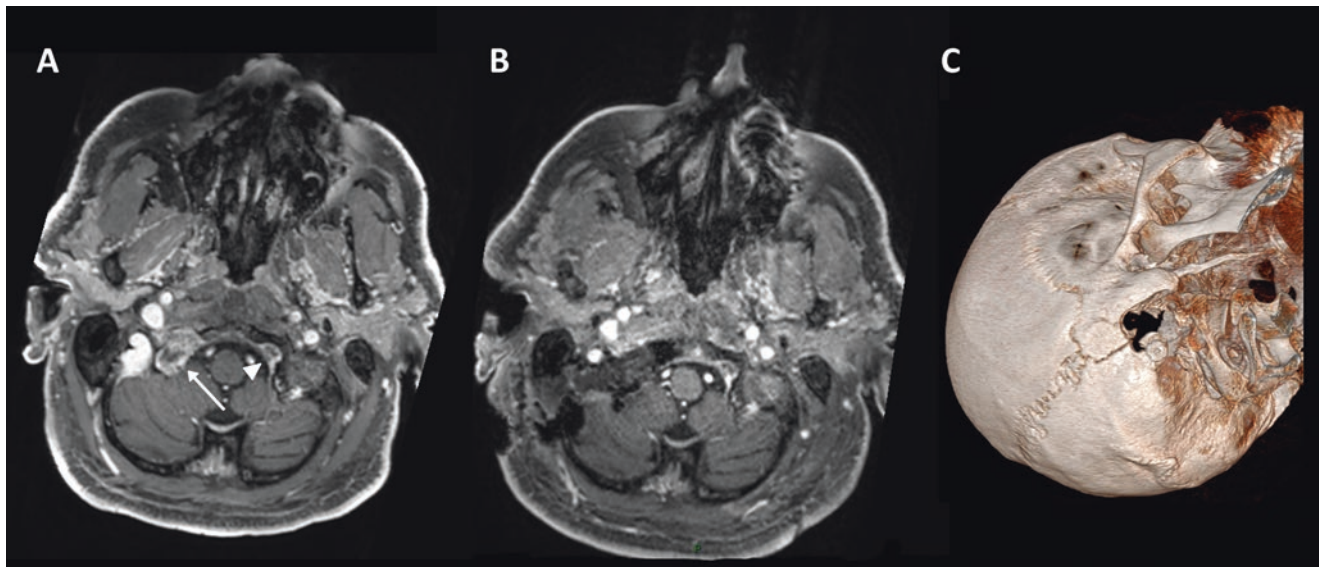
The first and foremost consideration in achieving an optimal resection in lesions affecting the lower clivus and CCJ, especially chordomas, is choosing the optimal surgical corridor. Although chordomas in this location are often midline, they also have the tendency to extend laterally and invade different compartments and anatomical structures around the skull base. More often than other lesions, chordomas at the level of the CCJ present an asymmetric growth pattern and are often comprised of multiple loculations. On occasion, this means that the straighter surgical corridor may not be the one that allows the most complete resection (Fig. 8.2a–c).

A detailed study of the preoperative images should be done by an experienced multidisciplinary skull base team. In tumor cases, we delineate and record all extensions of the lesion to be resected. We give particular attention to extensions causing compression of neurological structures

not well addressed by radiation therapy, such as the brainstem and optic chiasm, and those extending into bone or close to metallic reconstruction material.

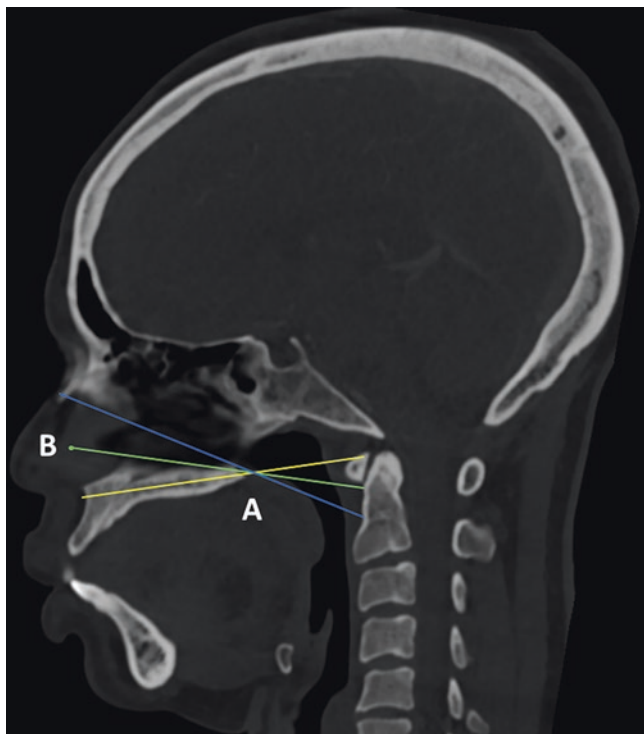
On the preoperative CT scan, a number of important elements must be considered in order to establish if an endoscopic endonasal route is appropriate and will allow for complete resection and/or sufficient neurological decompression (Fig. 8.3a, b). First, the palatine line must be drawn and the level of the tip of the odontoid marked. In the majority of patients, the tip of the odontoid falls into a  $\pm 3$  mm interval above or below the palatine line. The nasopalatine line, or Kassam line, between the rhinion and the posterior limit of the hard palate was first described to approximate the lower reach of an endonasal exposure. However, the nasopalatine line does not take into account the soft tissue retraction that is required to gain the down viewing angle and often overestimates the inferior limit of the exposure. We use the nasio-axial line (that connects the posterior limit of the hard palate with the midpoint between the rhinion and the anterior nasal spine) and has a better predictive value of the inferior limit of the dissection possible through an EEA [13].

The relationship of the lesion with the lower cranial nerves, namely, the 9th, 10th, and 11th nerves, at the level of the jugular foramen and the 12th cranial nerve in its hypoglossal canal is another critical element to establish preoperatively. In fact, these landmarks define the anatomical limitations to the coronal expansion of the endonasal corridor. They are also useful when considering a posterolateral approach as lesion compartments located ventromedial to



**Fig. 8.2** (a–c). Chordoma presenting unusual extension pattern and resection through keyhole far-lateral craniectomy. (a). MRI of a 59-year-old patient presenting with a late recurrence of a right jugular foramen chordoma (arrow) with extension to the contralateral hypoglossal canal (arrowhead). Clinically, the patient had complete right hypoglossal nerve

palsy. (b). Subtotal resection was achieved through a right keyhole far lateral approach with endoscopic assistance. Bony resection was done up until the level of the contralateral hypoglossal canal, but tumor was left in that location to avoid functionally unacceptable bilateral hypoglossal nerve palsy. (c). 3D reconstruction of the keyhole craniectomy



**Fig. 8.3** (AB). Preoperative assessment of EEA reach. The tip of the odontoid falls into a  $\pm 3$  mm interval above or below the *palatine line* (yellow line) in the majority of patients. The *nasopalatine line* (blue line) approximates the lower reach of an endonasal exposure, between the rhinion and the posterior limit of the hard palate (A). The *nasio-axial line* (green line), connecting the posterior limit of the hard palate (A) with the midpoint between the rhinion and the anterior nasal spine (B)

these are less well exposed and dissection and manipulation of cranial nerves could be required especially in case of an intradural extension medial to the cranial nerves. Neurological deficits, especially those involving cranial nerves and those that are deemed to have low rehabilitation potential, must be taken into consideration from a functional point of view in order to avoid catastrophic bilateral deficits such as bilateral hypoglossal palsy (i.e., case from Fig. 8.2a–c).

The surgical plan must take into account the patient's particular vascular anatomy and cerebral hemodynamics. In some cases, especially when there is encasement or suspected tumoral invasion of a major vessel, vertebral or carotid occlusion tests may be performed prior to surgical procedures.

Preoperative assessment of instability at the level of the CCJ with dynamic studies is required in all degenerative cases and some tumor cases. Even if the CCJ is deemed stable preoperatively, many cases of EEA and posterolateral approaches for CCJ chordomas that partially infiltrate the condyles mandate a posterior surgical stabilization and fusion surgery because of the additional resection of the condyle and periodontoid ligaments. In chordoma cases, fusion procedures should ideally be discussed and planned with the

radiation oncology team as metallic reconstruction material may be an obstacle to proper radiation treatment. In some patients, we have postponed the stabilization as a second stage after completion of proton beam irradiation, with external immobilization of the CCJ using a rigid collar during the proton beam therapy. Another option is to use carbon nonmetallic material which has become available for such indications.

## 8.5 Surgical Anatomy

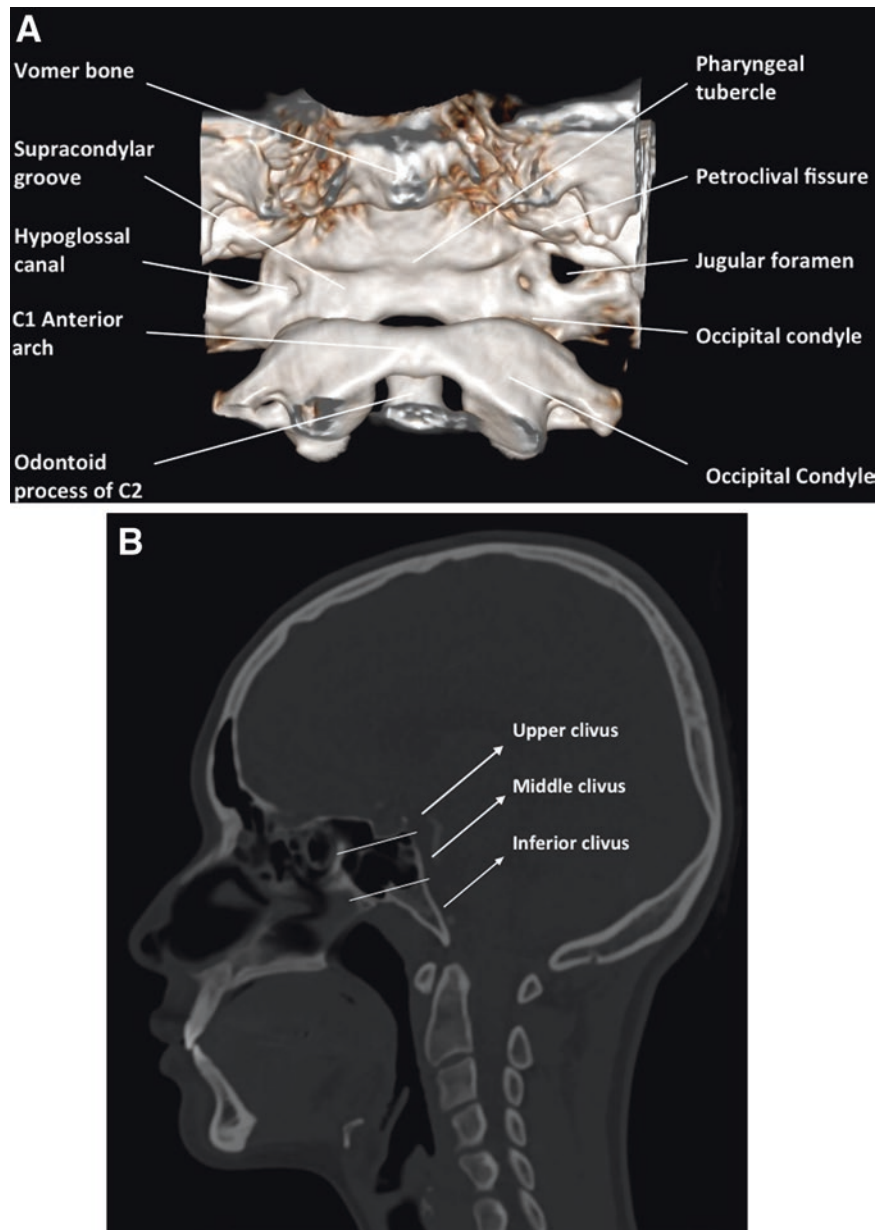
The use of technological adjuncts such as surgical navigation, cranial nerve monitoring, and Doppler ultrasonography, while useful and standard of care in such procedures, cannot replace a thorough and in-depth understanding of the anatomy of the anterior skull base and paranasal sinuses.

### Osteology

The clival bone is formed by the basilar part of the occipital bone and, at its superior third, by the sphenoid bone. These two parts are joined at the spheno-occipital synchondrosis, just inferior to the dorsum sella. The clivus is separated laterally from the petrous part of the temporal bone by the petro-occipital fissure (or petroclival fissure). Inferolaterally, it is continuous with the condylar parts of the occipital bone that form the anterolateral edges of the foramen magnum along with the clivus (Fig. 8.4a). Classically, the clival bone has been divided into three segments – upper, middle, and lower – although the landmarks delimiting these segments have been subject to some variation from one author to another. From the endonasal perspective, we find it is most useful to divide the clival bone according to lines passing at the level of the sellar and sphenoidal floors (Fig. 8.4b), as this classification correlates well with critical neurovascular relationships of the clival bone with the carotid arteries and intracranial structures and is surgically relevant.

On the exocranial surface of the clivus, the pharyngeal tubercle is found approximately 1 cm above and anterior to the edge of the foramen magnum on the midline. Another reliable osseous landmark is the supracondylar groove, a depression corresponding to the attachment of the rectus capitis anterior, and usually a few millimeters inferior to the level of the pharyngeal tubercle. It is useful in approximating the height of the hypoglossal canal and its external orifice, which are located just posterior and lateral to the supracondylar groove, respectively [14]. The occipital condyles articulate with the lateral masses of the atlas (C1). Their long axes follow an anteromedial trajectory, and their articular surfaces have an oval shape and face anterolaterally.

**Fig. 8.4** (a, b). Clival and craniocervical junction osteology



The condyle contains the hypoglossal canal, which encloses the nerve of the same name. The intracranial opening of the hypoglossal canal is located in the middle third of the condyle, and the canal has an anterolateral but also a slightly upward trajectory placing the exocranial exit just above the level of the condyle.

Ligaments located in the CCJ are particularly important in maintaining the dynamic stability of the junction. The anterior longitudinal ligament (anterior surface of C1 and C2 with continuation inferiorly), the anterior atlanto-occipital membrane (between C1 and the foramen magnum), and the apical ligament (between the tip of the dens and foramen magnum) are found from anterior to posterior. Bilaterally, the alar ligaments connect the dens with

the alar tubercles of the occipital condyles. The third ligamentous layer is formed by the cruciate ligament, with a vertical part and a horizontal part, also called the transverse ligament, attaching on the lateral masses of C1 on each side.

### Endonasal Landmarks

Careful study of the endonasal anatomy on the preoperative CT scan helps the operator in anticipating the patient-specific anatomy and identifying some surgically relevant anatomical variations (e.g., pneumatization of the sphenoid sinus, presence of Onodi cells, or dehiscent carotid canals). During surgery,

the first endonasal landmarks to identify are the choanal arches and the middle and inferior turbinates. The uncinate process, the bulla ethmoidalis, and the basal lamella can serve as guides to the superior aspect of the maxillary sinus, the medial wall of the orbit (lamina papyracea), and the posterior ethmoid, respectively.

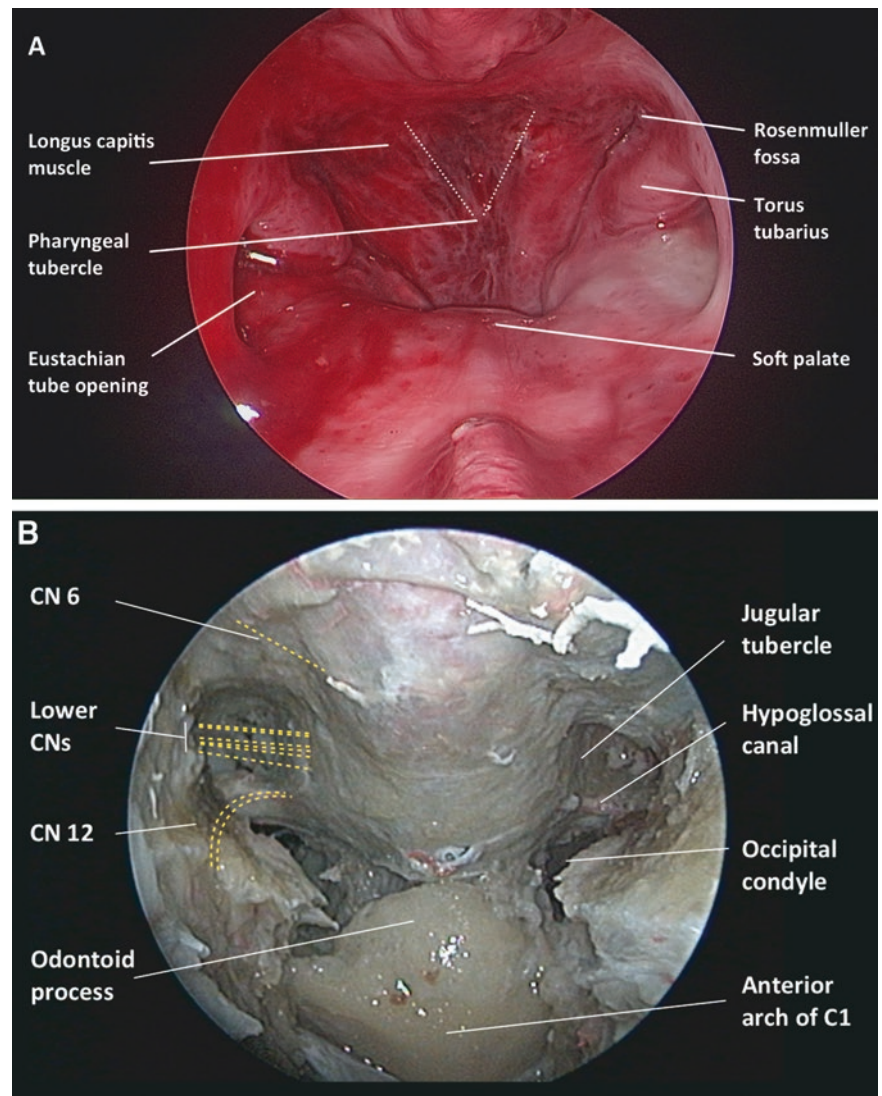
When following the nasal septum posteriorly, the rostrum of the sphenoid and the vomer bone are palpated. The ostium of the sphenoid sinus is found approximately 1.5 cm above the level of the choana. Just below passes the posterior septal branch of the sphenopalatine artery, which can be traced back to the sphenopalatine foramen. Below the choana, the openings of the Eustachian tubes are located anteriorly and inferiorly to the torus tubarius on the lateral wall of the nasopharynx (Fig. 8.5a). A line drawn between the upper edges of the Eustachian tube approximates the level of the foramen magnum. In the midline, the muscular insertion of the longus capitis muscle (which

overly and insert superiorly to the rectus capitis anterior) can be seen as a V-shaped prominence under the mucosal surface. The center of the prominence corresponds to the pharyngeal tubercle [15].

### Neurovascular Structures

Knowing the precise localization of the ICA is imperative at all times during endonasal procedures. The ICA is fixed in bony structures at its petrous (C2), lacerum (C3), and clinoidal (C5) segments but is mobile and easily displaced by tumors or other pathological processes in its cervical (C1) and cavernous (C4) segments. Moreover, anatomic variations of the ICA are frequent, including loops and anomalous locations, especially in the cervical segment where it is located deep in the soft tissues of the neck and where it is at risk of injury during expanded endonasal

**Fig. 8.5** (a, b). Endoscopic anatomy (cadaveric dissections)



procedures. It is thus critical that anatomical variations be recognized preoperatively on a CTA [16]. The paraclival ICA can be easily identified in many cases where there is a well-defined clival recess inferior to the sella. The vidian nerve can serve to define the depth and location of the ICA (C3 segment) as it terminates at the inferolateral edge of the lacerum segment of the ICA, between the petrous segment (C2) and posterior ascending segment (C4, or paraclival). Before its course in the petrous bone, the parapharyngeal ICA, or distal cervical segment of the ICA, can usually be found posterolateral to the deepest portion of the fossa of Rosenmuller. Although it remains a segment at risk, the parapharyngeal ICA is difficult to locate precisely intraoperatively. It is posterior to the lattermost extent of the cartilaginous part of the Eustachian tube and posterior to the levator veli palatini [17]. The parapharyngeal ICA position can also be approximated by a line going through the anteroposterior axis of the lateral pterygoid plate, which can also be confirmed on the preoperative CTA.

The abducens nerve, or CN VI, the main neurological structure at risk during endoscopic endonasal exposures, emerges on the medial aspect of the pontomedullary sulcus and after a superolateral cisternal course, enters Dorello's canal, an interdural space. The nerve courses under the petrosphenoid ligament (Gruber's ligament) and runs more horizontally lateral to the posterior ascending or paraclival segment of the cavernous carotid to enter the cavernous sinus where it ascends again immediately inferior and lateral to the anterior ascending segment of the ICA. The glossopharyngeal nerve (CN IX) courses in a separate compartment of the jugular foramen than the vagal (CN X) and accessory (CN XI) nerves, the anteromedial *pars nervosa* and the posterolateral *pars vasculosa*, respectively. The hypoglossal nerve (CN XII) arises at the pre-olivary sulcus and has an upward and lateral trajectory toward the hypoglossal canal. After its exit from the exocranial end of the canal, it follows the lateral margin of the rectus capitis anterior muscle (Fig. 8.5b).

## 8.6 Surgical Technique

### Endoscopic Endonasal Approach

As in other complex interventions, a clearly defined surgical strategy is a key factor in gaining proficiency and improving the safety of the procedures performed. Elements to be defined preoperatively can be broken down into three main elements: (1) exposure, (2) resection, and (3) reconstruction [18]. As previously mentioned, the main difficulties in endoscopic endonasal approaches are control of the 6th and 12th cranial nerves and the parapharyngeal ICA. Optimization of the exposure is done by establishing which surgical corridor

is best suited for the lesion to be treated (covered in this chapter under "Patient Selection"), but also by planning for extensions of the approach that can improve tumor exposure and neurovascular control. This is part of the "modular" or "building blocks" philosophy that is well described for EEA.

To achieve more complete resections, it is imperative to define all extensions of the tumor according to certain anatomic landmarks (i.e., paraclival carotid artery, hypoglossal canal, odontoid process, etc.). We often prepare a list of targets preoperatively with associated surgical maneuvers or extensions to the approach to perform in order to reach each tumor sub-compartment.

Reconstruction is often the step that leads to the most problematic complications postoperatively, and therefore it must be planned for and executed with careful attention. It is important to consider if previous surgeries were performed and, if so, how reconstruction was achieved and if the mucosal flap can be reutilized. In some cases, a laterally extending approach is required, and a NSF cannot be utilized on that side and must be harvested contralaterally. In situations in which both sphenopalatine arteries are compromised, an alternate vascularized grafting material should be sought for and planned. For example, in some cases with multiple previous surgeries and/or radiation therapy, the best reconstruction material is a temporoparietal fascia flap that mandates a different positioning and preoperative preparation. This particular flap also requires a maxillary antrostomy and transpterygoid dissection, which can also be used to increase the working space inside the nasal cavity. However, in those cases, where the closure may be challenging and requires additional cranial incision and work, a classic transcranial approach should also be considered.

### Operative Setup and Patient Positioning

The positioning of the patient should allow for a comfortable and ergonomic position for both surgeons. An ideal setup is comprised of two high-definition (HD) screens, each facing one of the surgeons, who are usually on the right side of the patient (for right-handed surgeons). We also like to have the scrub nurse positioned in front of the surgical team on the other side of the patient to allow for safe and easy handling of the instrumentation. The anesthesia team is usually at the feet of the patient.

The head is positioned in a fixed head holder to avoid surgeon disorientation and loss of optimal positioning. More importantly, the head is flexed, rotated, and tilted toward the side of the surgical team. The rotation and tilt are especially important to center the head in the field of view and action of the surgeons. A practical rule of thumb to estimate the degree of tilt required is to align the patient's head with the ipsilateral nipple. Slight head flexion is also strongly recommended as it grants better exposure of lower clival and CCJ pathologies (unless a temporoparietal fascia



flap is needed). To ensure good venous outflow and to reduce venous bleeding, we usually elevate the head and thorax, in addition to a slight reverse Trendelenburg positioning of the surgical table. The abdomen and/or anterolateral thigh are prepared for harvesting a fat and/or fascia lata graft to repair the bony and dural defects.

### Instrumentation

In our practice, we have taken up the habit of using almost exclusively 4 mm 30° and inverted 30° scopes (Karl Storz™) in our endoscopic cases. Using the angled scopes from the beginning of the surgery grants the surgeon an almost instinctive understanding of the anatomy under angled visualization, allowing him to make full use of the advantage of endoscopy in terms of panoramic exposure and leaves more room for instrument maneuvering away from the scope. The 45°, 70°, and the EndoCAMEleon® scopes (Karl Storz, Tuttlingen, Germany), with an adjustable viewing angle, are also very helpful in reaching lesions located inferiorly or laterally, typically behind the horizontal segment of the ICA.

Angled and length-appropriate instrumentation are a must in extensions of the endoscopic endonasal approach. While the angled endoscopes provide the visualization, angled instruments, especially malleable rotatable suction-tips, provide the necessary maneuverability to resect laterally reaching compartments of the lesion. Long angled and self-irrigating drill bits are also useful in reaching the lower clival and upper cervical regions.

In all EEA cases, we use surgical navigation with both MRI (T2 weighted or CISS/FIESTA and T1 weighted with gadolinium) and CT imaging fusion. Similarly, the microvascular ultrasound Doppler probe is used systematically to accurately localize the internal carotid and sphenopalatine arteries. The precision of the navigation system should be confirmed regularly during the procedure and must be used carefully and in conjunction with anatomical landmarks.

Another technological adjunct indispensable in EEA is electromyographic (EMG) monitoring of cranial nerves. In chordoma cases, we usually monitor at least both 6th nerves. Additionally, the 5th nerve is usually monitored on the side of a transpterygoid approach, as well as the 12th nerves (bilaterally) and lower cranial nerves (10th and 11th), depending on the tumor extensions and planned surgical exposure. An alternative to EMG monitoring of the nerves innervating the extraocular muscles is electrooculography (EOG) that can be used to detect vertical and horizontal movements of the eye globe.

### Technique

In many lower clival cases, a two-surgeon, four-hand technique is employed. The obvious advantage of this setup is the finer dissection that can be accomplished with two instruments. A binostril access and wide septostomy and sphenoidotomy

are required to gain adequate maneuverability for both surgeons. However, we now strive to limit as much as possible the endonasal morbidity and have used a uninarial access in many, if not the majority, of our most recent endonasal lower clival cases (detailed below under [Minimally Invasive Endonasal Access and Mucosa-Preserving Surgery](#)).

The first step, similar to every endonasal case, is to identify the relevant anatomy and key landmarks, including the choanal arches, the middle and inferior turbinates and sphenoid ostia. A middle turbinectomy can be done on one side, usually on the right, as it provides increased space for the endoscope and suction but it is not always required. The inferior turbinates are preserved in most cases, but it may be useful to down-fracture them to enlarge the endonasal corridor when aiming at lower lesions. The mucosa of the inferior turbinate can also be a valuable vascularized flap option for reconstruction if the NSF is not available [19]. The middle turbinectomy is followed by a maxillary antrostomy, accomplished by identifying and resecting the inferior aspect of the uncinate process. The medial wall of the maxillary sinus is then resected from front to back with a back-biting instrument

A posterior ethmoidectomy facilitates identification of the anatomical landmarks relevant to the harvest of the nasoseptal flap and is helpful when the lesion to be treated is located higher up in the clivus or invades the sphenoid sinus. The bulla ethmoidalis is resected, and the basal lamella of the middle turbinate is opened to gain access to the posterior ethmoid. The lamina papyracea, which is the lateral wall of the bulla, is identified and serves as the lateral limit of the ethmoidectomy. Identifying the sphenoid ostium before resecting the basal lamella is valuable in preserving the posterior septal artery (PSA) and a large mucosal pedicle for the NSF.

Harvesting the NSF is done in a standard fashion, with particular attention given to preservation of the olfactory mucosa. It is also important to try and tailor the flap to the expected dural defect and structures to be covered. Extending the NSF by including nasal floor mucosa and mucosa of the inferior meatus and planning a contralateral NSF flap are options that must be entertained and prepared at this stage of the operation. As discussed previously, when a transpterygoid dissection is planned, the NSF is most often harvested on the contralateral side. Otherwise, it is necessary to free the flap's pedicle along with the sphenopalatine fossa, after sectioning the vidian nerve in order to be able to lateralize the flap sufficiently. The harvested NSF is placed in the maxillary sinus and held in place with the aid of large cottonoids. At this point, a wide posterior septectomy is done, followed by resection of the keel of the sphenoid bone, either with the drill or osteotomes, which have the added benefit of providing bony material for closure. The sphenoid anatomy is explored and the opening is widened to identify the lateral recesses

of the sphenoid bilaterally, the paraclival internal carotid arteries (ICA), the sella and optic nerves, the optico-carotid recesses, and the clival recess.

Extensive drilling of the floor of the sphenoid sinus and the clival bone can then be done quickly with a large coarse diamond drill, while keeping track of the exact location of both ICAs and after appreciating the depth of the dural plane. A diamond drill and continuous irrigation should be used when drilling over the ICA and dura mater, preferentially with a large drill bit.

To access the lower third of the clivus and the CCJ, partial/total resection or downward retraction of the muscles attaching to the clivus, namely, the longus capitis and the rectus capitis anterior, is required. In chordoma cases, there are frequently tumor loculations in these muscles, and partial resection of the pre-clival soft tissues is often preferable to achieve gross total resection. In this region, the most reliable landmarks are the Eustachian tubes, which indicate the lateral limit of the surgical exposure and help define the midline. The parapharyngeal ICAs are usually located lateral and posterior to the Eustachian tubes, but this must be verified on preoperative vascular imaging to avoid being surprised during surgery by a medially oriented vascular loop.

Opening and resection of the dura depends on the location and type of pathology. In chordoma surgery, it is often possible to predict if there is dural transgression with T2-weighted images on MRI. During surgery, when the dural transgression is not obvious, indirect signs are the absence of venous bleeding from the venous channels of the clival plexus after completion of clival drilling and splitting of the dura's layers. It is not clear if resection of dural "margins" is required or if it has a survival benefit. When there is no clear dural penetration, coagulation of the attachment base is undertaken while avoiding heat injury to the abducens nerves. In some instances, it is possible to find a dissection plane between the chordoma-infiltrated periosteal layer of the dura mater and an intact meningeal layer, which may allow for a complete resection without dural breach. Radical resection of the dura is reasonable only if complete resection of the intradural extension is achievable, which is not always the case due to brainstem infiltration. In those cases, it is better to keep the dural opening as small as possible to facilitate closure.

### **Chordoma Resection (Fig. 8.6a–l)**

Chordomas are soft, easily aspirated lobulated tumors. The use of an ultrasonic aspirator is often not necessary, although a rotating aspirator tip may prove useful, particularly if used under angled endoscopic visualization. It is not always necessary to perform an extracapsular dissection since there is no "true" tumor capsule in most chordomas. Piecemeal resection often allows safer tumor removal without compromising GTR. The pseudocapsule that is oftentimes identified

is usually a conjunctive inflammatory reaction around the tumor that can be aspirated along with the tumor. In the rare occurrences that the chordoma is found to be fibrous, we have found that GTR is hard to achieve safely since these lesions are also more adherent to the ICA and cranial nerves.

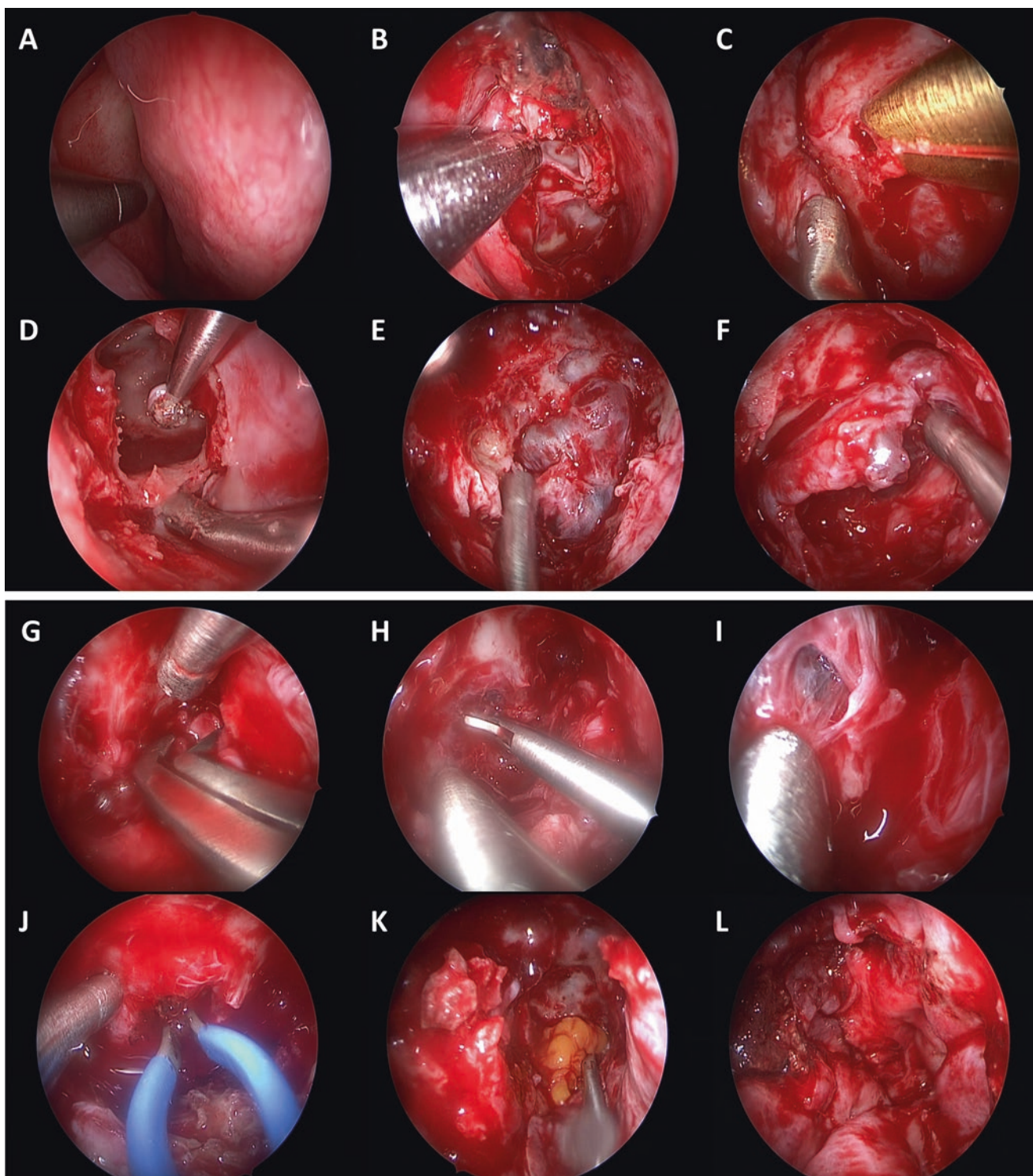
During tumor resection, every precaution should be taken to limit tumor seeding in the CSF, but even more so through the surgical corridor. In fact, these tumors are known to have the propensity for metastasizing through both routes, and as a general rule, intratumoral debulking must be maximized before intradural exploration. We also try to limit irrigation when dealing with the intradural compartments of the lesion. As for surgical corridor dissemination, it can probably be minimized by careful inspection and abundant irrigation at the end of the case when the reconstruction has been satisfactorily carried out and the intradural compartment effectively sealed. Likewise, in order to reduce the occurrence of avoidable tumor seeding, biopsy of clivus lesions, when imaging features are highly evocative of chordoma, should be avoided in most cases.

Since chordomas arise from notochordal remnants in the cancellous bone of the clivus, it is important to resect as much of the involved bone as possible. This aspect of the resection is too often neglected. It is reasonable to assume that delayed recurrences after GTR could be due to chordoma cells left in the cancellous bone surrounding the initial "visible" tumor.

### **Minimally Invasive Endonasal Access and Mucosa-Preserving Surgery**

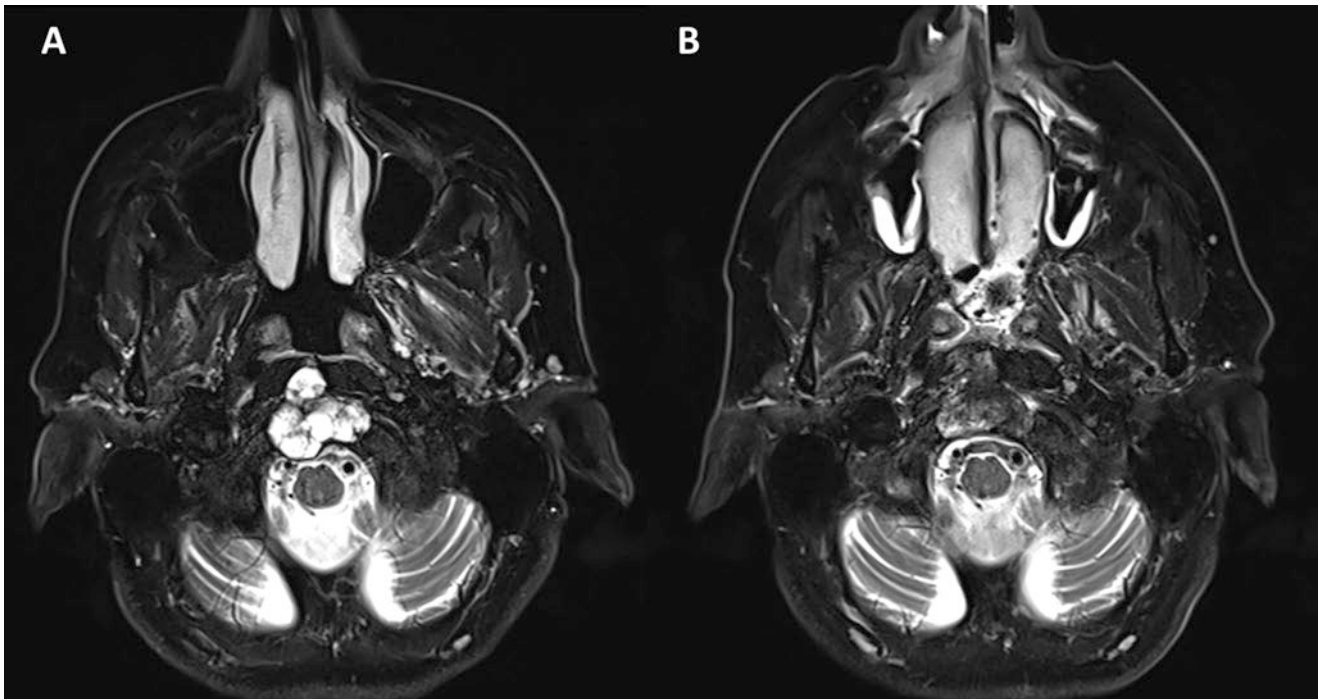
In some cases, it is possible to achieve gross total resection with a uninarial technique and with minimal disruption of the endonasal anatomy (Figs. 8.6a–l and 8.7a, b). While the occurrence of true "empty nose" syndromes is rare, limiting endonasal morbidity clearly improves patient quality of life in the postoperative period. Undoubtedly, the binarial transseptal approach can be "maximally invasive" for the endonasal anatomy, and such extensive dissections are not required in the majority of cases. Nonetheless, going through one nostril and limiting one's approach must not be done at the expense of the quality of the resection.

Uninarial access usually provides sufficient room for only one surgeon, although a third hand to control the suction may be useful in certain stages of the surgery (e.g., drilling and fine dissection). In uninarial access, the hand navigating the endoscope can also be used to hold and control a rotatable suction tip, leaving the dominant hand with the control of another instrument. Although this technique often used by the senior author requires some adaptation and learning curve, it is especially useful in minimally invasive endonasal exposures. Using this technique, the conflict between other instruments and the endoscope is limited, and the endonasal structures that are kept intact serve as a funnel



**Fig. 8.6** (a–l). Endoscopic resection of a chordoma of the lower clivus. 56-year-old woman with a clival chordoma. Step-by-step description of the endoscopic endonasal exposure and resection of the tumor through a unilateral corridor. (a). The middle turbinate is outfractured after identification of the endonasal anatomy. (b). After middle turbinectomy, a posterior ethmoidectomy is undertaken with the shaver. (c). Posterior septectomy with preservation of the contralateral mucosa. (d). A large sphenoidotomy is completed with a large coarse diamond drill and Kerrison rongeurs. (e). Extensive drilling of the clivus is done, exposing the extracapsular plane of the tumor. (f). The chordoma is debulked,

taking care to limit tumor spillage to avoid surgical corridor seeding. (g). In lower clivus chordomas, such as in this case, extensions in the longus capitis and rectus capitis anterior muscles must be sought. (h). The dura mater is split into its two layers to make certain that all the tumor extensions have been resected. (i). A small area of dural defect if exposed with the underlying arachnoid. (j). Coagulation of the dural and muscular margins after gross total resection. (k). A fat graft is placed to fill the drilled clival bone. (l). A NSF is harvested on the contralateral side and is placed over the fat graft and supplemented with fibrin glue



**Fig. 8.7** (a, b). Tailored endoscopic endonasal resection of clival chordoma. (a) Preoperative and (b) postoperative images of an endoscopic endonasal resection of a chordoma of the lower third of the clivus.

Gross total resection was achieved through a left uninarial approach with preservation of the anterior two-thirds of the nasal septal mucosa bilaterally and all turbinates except the left middle turbinate

for the endoscope. The narrower the corridor is, the easier it is to manipulate the instruments. Another advantage is to have the endoscope extremely close to the tip of the instruments.

A contralateral trajectory in lesions extending preferentially on one side may be a valuable option. To gain adequate access to lower clival lesions through one nostril, a middle turbinectomy is usually necessary. The posterior bony septum can be partially resected, but a simple pushover on the other side of the septum along with the contralateral mucosa generally suffices. A wide sphenoidotomy is unavoidable, however, to provide room for both the endoscope and instruments. A posterior ethmoidectomy can also be quite useful to gain additional space to maneuver the instruments without interference from the endoscope. If a NSF is required, it must be harvested on the side of the exposure, which also means that a transpterygoid approach is not feasible if the sphenopalatine artery is to be preserved.

### Extending the Surgical Corridor Laterally

Extending the corridor laterally also means that the ICA will be exposed and will have to be managed on a longer segment. A transpterygoid approach helps gain the lateral visualization required to better define the ICA's course. After a wide maxillary antrostomy, the posterior wall of the maxillary sinus is resected. The pterygopalatine ganglion (PPG) and surrounding soft tissues are kept inside the peri-

osteum, which is dissected laterally, and the greater palatine nerve is identified going down. This nerve has a predictable downward trajectory and can be skeletonized out of its bony canal to allow for increased mobilization of the pterygopalatine fossa (PPF). Its sacrifice can result in uncomfortable hypoesthesia in the hard palate and should be avoided if possible, especially if only the superior aspect of the pterygoid has to be removed. The sphenopalatine branch is identified, coagulated and sectioned at its exit from the sphenopalatine foramen after elevating the mucosa anterior to the foramen. After mobilizing the PPF laterally, the vidian canal bundle is progressively identified. Section of the vidian nerve allows for increased lateral mobilization of the PPF. Frequently, before identifying the VN, another bundle is seen, composed of the palatovaginal artery and nerve, which have a more medial direction. It should not be confounded with the vidian canal bundle. The root and medial plate of the pterygoid can then be drilled to increase access inferolaterally in the sphenoid bone and expose the foramen lacerum.

The transpterygoid approach allows better identification of the lacerum segment of the ICA and to gain lateral working space in the middle clivus and petrous apex areas. However, to obtain a more lateral exposure lower in the clivus or at the CCJ, downward mobilization or resection of the Eustachian tube must be done with drilling of the medial plate of the pterygoid. After identification of the

foramen lacerum, and clearly defining the limits of the anterior genu of the ICA with a micro-Doppler, a cut in the cartilaginous portion of the Eustachian tube is done below the lacerum segment.

### Extending the Surgical Corridor Inferiorly

To increase exposure down to the lower third of the clivus and the upper cervical region, certain simple maneuvers can be done such as outfracturing the inferior turbinates and putting slight retraction on a stitch placed in the soft palate. However, to be able to decompress and resect pathology in the CCJ, some specific landmarks are useful to extend the bony resection to its neurovascular boundaries. One of such landmarks is the supracondylar groove (or inferior clival line), which marks the approximate height of the hypoglossal canal. To better delineate this groove, the muscles are either dissected subperiosteally or resected. Drilling the anteromedial aspect of the condyle and thus skeletonizing the hypoglossal canal lead to inferior delineation of the jugular tubercle, which separates the hypoglossal canal from the jugular foramen. While the hypoglossal canal can be exposed through a midline corridor, unroofing the jugular foramen often requires a lateral dissection with a transpterygoid approach and resection of the Eustachian tube. In certain cases, where the condylar bone has been invaded and eroded, this exposure is already done by the tumor, and simple internal debulking is enough to expose both the lower cranial nerves and the 12th nerve in their dural sleeves. Lateral limits to bone drilling and intradural exposure are the inferior petrosal sinus, which courses along the intracranial aspect of the petroclival fissure and the vertebral artery when the drilling involves C1 and C2.

### Endoscopic Odontoidectomy

To access the odontoid and perform an endoscopic anterior high cervical decompression, a less invasive endonasal approach is often sufficient. Through a binostril access, we begin by outfracturing the inferior and middle turbinates. In certain cases, partial posterior septectomy may be required to gain adequate exposure posteriorly and under the choanal arches. To increase the inferior angle, a stitch is placed in the soft palate and retracted through the mouth.

The nasopharyngeal mucosa and underlying muscle can either be reclined in a “U”-shaped flap or incised in the midline and dissected laterally. In our opinion, the midline incision is probably the most direct and least traumatic option and often allows for sufficient exposure and satisfactory closure. It can also be easily extended if need be. The pharyngeal tubercle is a reliable landmark to approximate the level of the foramen magnum (1 cm below). Under the longus capitis, the anterior atlanto-occipital membrane is either dissected laterally or resected. At this point, the anterior arch of C1 is visible and can be drilled to expose the dens. After

disconnecting the odontoid process from its ligamentous attachments, it is removed with an “eggshell” technique. The apical, alar, and transverse ligaments are then resected, taking particular care in preserving the underlying dura.

After careful hemostasis, and if no CSF leak has been encountered, it is generally sufficient to line the surgical cavity with absorbable hemostatic agents (e.g., Surgicel©, Ethicon, Somerville, NJ, USA). If there is a CSF leak, a NSF is harvested and positioned over the dural defect, after multilayered closure (TachoSil© [Baxter Healthcare Corp, Deerfield, IL, USA] and a fat graft).

### Reconstruction

A well thought through reconstruction is an essential part of the preoperative surgical strategy. Whenever there is a dural defect to reconstruct, a multilayer technique is employed. We first put fascia lata as onlay or with a “gasket seal” technique. Fibrin glue and TachoSil© are used as sealants and holding material. In the clival area, a fat graft is placed in virtually every case to fill the void left by the clival drilling. This probably reduces the occurrence of encephalocele over the long term, which can be quite dramatic in this location with anterior displacement of the brainstem or the vertebrobasilar system. Finally, a vascularized flap is placed over the fat graft and serves as the main element contributing to long-term watertight closure.

The mainstay in terms of vascular graft is obviously the NSF. However, there are other options if the nasal septum has been compromised by previous surgery or radiation. In some instances, we have used a “U”-shaped nasopharyngeal mucosa flap, based inferiorly on branches of the ascending pharyngeal and the Eustachian branch of the accessory meningeal artery and rising as high up as the sphenoid ostia and extending laterally to the level of the sphenopalatine foramina. If the mucosa is thick enough, an inferior turbinate flap can be elevated in place of a NSF. As a last resort, we have used the temporoparietal fascia flap, which can be tunneled in the nasal cavity through the pterygopalatine fossa. We do not favor nasal packing in the majority of the patients, although in some cases, we use a silastic patch to hold the vascularized graft in place.

### Keyhole Concept in Posterolateral Approaches to the Lower Clivus and High Cervical Region

The keyhole concept can also be applied to posterolateral approaches to the clivus and CCJ, including the far-lateral craniotomy and high lateral cervical approaches. In these skull base exposures, due to the intervening muscular layers to be dissected and the vascular anatomy to be managed, it is not always possible to use limited skin incisions. However, minimal invasiveness is not only about limiting the skin

incision. It must be remembered that the keyhole is not necessarily placed at the surface. Following a “hockey stick” incision and exposure of the occipital bone and condyle, a deep keyhole, located in the condylar fossa, for example, can provide access to a large segment of the middle and lower clivus and C1 and C2 vertebrae (Fig. 8.1a, b) with the assistance of the endoscope to browse this area.

We have been recently revisiting our surgical strategy in lower clival lesions, especially in cases where the dural defect is expected to be large and the CSF leak risk deemed high. In some revision cases, reconstructive options may be limited. We also have preferred transcranial approaches in cases where, based on imaging studies, an intracranial component of the lesion appears adherent to the brainstem or neurovascular structures and the microsurgical dissection stage is expected to be complex. The posterolateral transcondylar route is a good option in such cases. In situations where an occipitocervical fusion is necessary, this route also has the advantage of using the same midline skin incision. Conversely, the fusion procedure can also be utilized as an occasion to perform additional tumoral resection from a different trajectory.

### Technique

The posterolateral transcondylar approach can be tailored to be both minimally invasive and give maximal exposure of the pathology at hand. We have used both limited skin incisions (“lazy S” and “C shaped”) and the classic “hockey stick” incision for these approaches, depending on the surgical trajectory. We have found the “hockey stick” incision to be helpful in cases where the vertebral artery was involved with the tumor (either encased or displaced) and in tumors with an extension higher up in the clivus. With a well-devised approach, the surgeon can reach tumor extensions located as high as the upper third of the clivus and within the sphenoid sinus. We also use the “hockey stick” incision when an occipitocervical fusion is required.

If a small skin incision is used, the muscular stage of the surgical dissection needs to provide a flat surgical field. In a way, the dissection of the muscles of the retromastoid and condylar fossa is similar to that of the temporalis muscle when performing a pterional or orbito-zygomatic craniotomy. To do so, we first disinsert and recline the sternocleidomastoid muscle from the mastoid, followed by the splenius capitis and longissimus capitis muscles. Underneath, the posterior belly of the digastric muscle and the muscles of the suboccipital triangles can be identified. The superior oblique muscle can be disconnected from the occipital bone to expose the retrocondylar fossa.

At this point, important bony landmarks should be identified, the mastoid tip and digastric groove anteriorly and the occipital condyle and the C0-C1 joint and the foramen magnum medially and posteriorly. The third segment of the ver-

tebral artery is located at this stage. A small inferiorly placed retrosigmoid craniotomy can then be performed, with subsequent drilling of the posterior part of the mastoid to increase exposure of the sigmoid sinus down to the jugular bulb.

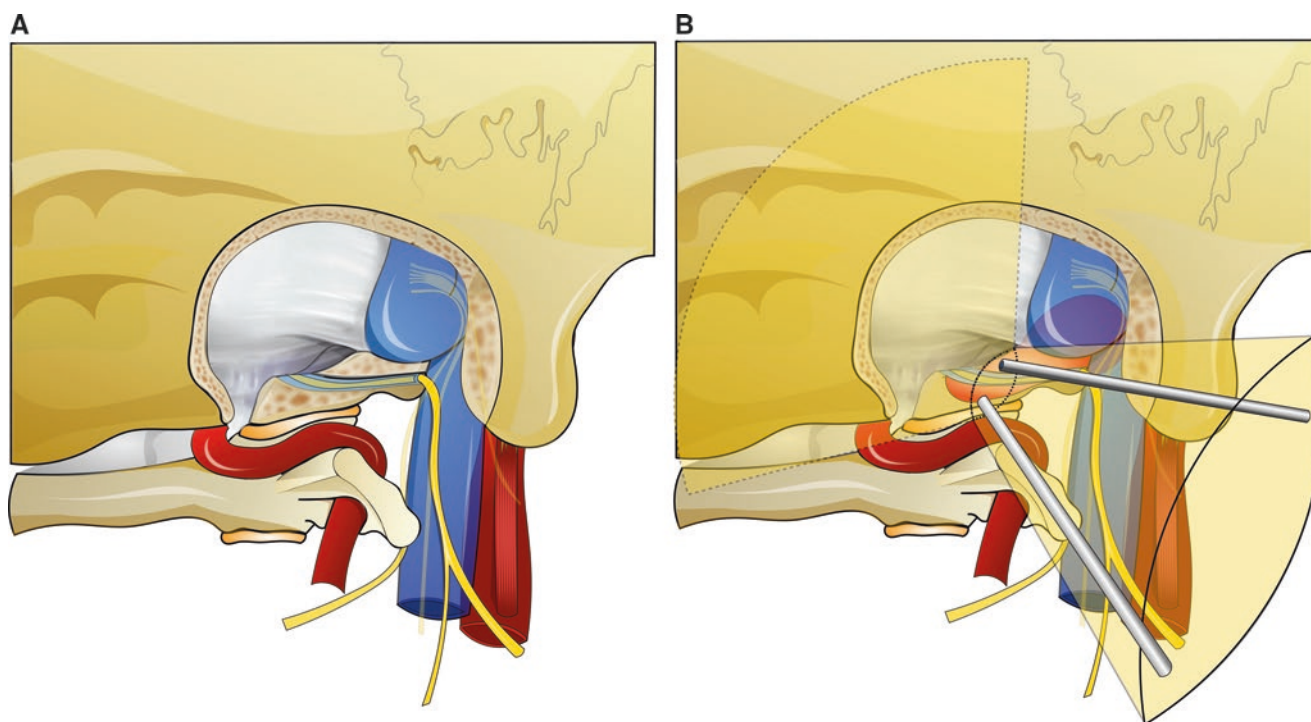
In addition to classic skull base techniques such as drilling the jugular tubercle and mobilization of the vertebral artery, the use of endoscopic assistance has also proven to be an invaluable tool to increase the reach of these approaches (Fig. 8.1a, b). The endoscope should be used as a tool to navigate and operate in the depths of the triangles defined by the lower cranial nerves. In chordoma cases, this is safely accomplished in the extradural compartment, in the space left by the drilling or tumoral osteolysis of the condyle and jugular tubercle, superiorly to the 12th nerve and inferomedially to the jugular bulb and inferiorly to the 12th nerve and superiorly to the third segment of the vertebral artery (Fig. 8.8a, b). The endoscope increases both illumination and visualization in these deep locations and can help reach as far as the petrous apex and sphenoid sinus through the condylar keyhole. In soft tumors, the surgeon can easily aspirate and debulk tumors compartments with the endoscope in one hand and a malleable suction tip in the dominant hand.

### Role of Neurophysiology

In addition to electromyographic (EMG) monitoring of the 6th, 9th, 10th, and 12th nerves, motor and sensory evoked potentials are utilized in cases of brainstem compression. In some tumor cases, including chordomas, the clival bone is eroded and bony landmarks are lost. In these situations, direct stimulation with an EMG probe can be useful in cranial nerve identification and preservation (especially 6th cranial nerve). Neurophysiological monitoring with somatosensory evoked potentials (SSEPs) and motor evoked potentials (MEPs) also has a pivotal role during the surgical positioning of unstable high cervical lesions.

## 8.7 Postoperative Care / Complications

In the postoperative period, patients must be monitored for the development of CSF leak, meningitis, and neurological symptoms. We do not routinely leave lumbar drains or continue antibiotics after surgery, although we do occasionally perform evacuative lumbar punctures if patients complain of headaches or in cases of ventricular dilation on postoperative imaging. All patients should have an MRI in the first 48 h following tumor surgery to assess the extent of resection and allow, when indicated, a second surgical stage to be discussed or proton beam therapy to be planned without delay. Specific complications of the EEA approach to the lower clival and the CCJ region include velopharyngeal insufficiency (especially when the soft palate is split), CSF leak, meningitis, and wound dehiscence and infection [20].



**Fig. 8.8** (a, b). Anatomy and endoscopic windows through extradural triangles in the retrocondylar fossa. (a). Exposure of the retrocondylar fossa and identification of the C0-C1 joint, the third segment of the vertebral artery, the sigmoid sinus and jugular bulb, and the suboccipital and foramen magnum dura. The 12th nerve, inside its dural sleeve, has been exposed after drilling of the occipital condyle. (b). In the extradu-

ral compartment, two windows can be used to access lesions involving the lower and middle thirds of the clivus and the dens and lateral masses of C1. The first space is located superiorly to the 12th nerve, inferomedially to the jugular bulb, and is limited medially by the dura. The second window is inferior to the 12th nerve, superior to the third segment of the vertebral artery, and is also bounded medially by the dura

Endoscopic follow-up for control of mucosal healing, flap intake and vascularization, and removal of crusting must be done during the initial hospitalization and then at regular intervals until satisfactory healing is documented. If a CSF leak occurs in the immediate postoperative period, our first line of treatment is usually bed rest and lumbar drainage, unless the leak is deemed to be “high flow.” In such cases, immediate surgical reexploration is undertaken, and graft repositioning or replacement is done. After anterior endoscopic odontoidectomy, the patient is fed through a nasogastric tube placed under direct visualization at the end of the procedure for a period of 5 days to allow for wound healing.

### Carotid Injury

Intraoperative internal carotid injury is the most feared complication of EEA in lower clival and CCJ pathologies. A CT angiography should be considered systematically in these cases as it offers a precise evaluation of the main intra- and extracranial vessel trajectories (ICA in all its segments, vertebral and basilar arteries, posterior and anterior

communicating arteries) as well as their relationship with the tumor. The need for proximal control of the ICA prior to tumor resection must also be anticipated especially when the tumor is extending laterally and posteriorly to the paraclyval ICA. In such cases, an additional transpterygoid approach, following the vidian nerve posteriorly toward the lacerum segment of the ICA, may be necessary before tumor resection. It is important to take into account tumor pathology and invasiveness, as well as prior irradiation, as these factors may be associated with weaker arterial walls and a higher injury risk.

The initial response should be to initiate resuscitation efforts and prepare for massive transfusions on the anesthesia side as well as regain visualization and control of the surgical field, usually with packing. Surgical hemostasis is then obtained, with options including tamponing with crushed muscle, direct suture repair, or clipping. Once hemostasis has been achieved, an immediate angiographic assessment should be sought. Endovascular options in the acute setting are either ICA occlusion or endoluminal reconstruction. Variables to consider when deciding which to choose include the extent and morphology of ICA injury, surgical control of the bleeding, patient

factors (age, comorbidities, etc.), angiographic findings (active bleeding, pseudoaneurysm width and morphology, etc.), vascular anatomy and collaterals and, most importantly, expected tolerance of antiplatelet therapy.

### Craniocervical Junction Instability

Preoperative assessment of dynamic stability of the CCJ is required in the majority of cases, irrespective of the etiology. When clivectomy and complete condylectomy or odontoidectomy have been undertaken, posterior stabilization is indicated. In cases of partial condylectomy, opinions differ between authors as to the amount of occipital condyle that can be resected before instability is encountered. A recent cadaveric study has suggested that a threshold of 75% anterior condylectomy may be associated with clinical significant hypermobility [21]. Ligamentous resection can also be responsible for instability at the CCJ, particularly when alar ligaments or transverse ligaments are rendered incompetent.

It has been our practice to undertake the posterior stabilization in the early days after the anterior stage in most cases. Some authors advocate doing the posterior fusion in the same surgical sitting, while others even recommend that the fusion precede the anterior decompression. In certain chordoma cases, we even prefer doing the fusion after the proton beam therapy, since the artifacts from the instrumentation have a significant impact on the planning and delivery of the radiation therapy. Neuromonitoring, including lower cranial nerves, MEPs, and SSEPs, is useful during the positioning for the second surgical stage.

### 8.8 Surgical Pearls

- A detailed study of preoperative imaging is imperative to perform safe endoscopic endonasal procedures. It allows for identification of anatomical variants (including the ICA), inventory of all tumor compartments to be resected, and planning for reconstruction material.
- Precise understanding of ICA anatomy is crucial during endonasal procedures. Key landmarks for its location are the vidian nerve and the Eustachian tube.
- In many endoscopic endonasal approaches for clival lesions, it is possible to achieve gross total resection through a uniaxial access and with minimal disruption of the endonasal anatomy.
- The keyhole concept can be applied to posterolateral approaches to the clivus and CCJ, including the far-lateral craniotomy and high lateral cervical approaches with the help of endoscopic assistance.

### References

1. Dlouhy BJ, Dahdaleh NS, Menezes AH. Evolution of transoral approaches, endoscopic endonasal approaches, and reduction strategies for treatment of craniocervical junction pathology: a treatment algorithm update. *Neurosurg Focus*. 2015;38(4):E8.
2. Jho HD, Carrau RL. Endoscopy assisted transsphenoidal surgery for pituitary adenoma. Technical note. *Acta Neurochir*. 1996;138(12):1416–25.
3. Jho HD, Carrau RL, McLaughlin MR, Somaza SC. Endoscopic transsphenoidal resection of a large chordoma in the posterior fossa. *Acta Neurochirurgica*. 1997;139(4):343–7; discussion 7–8.
4. Frempong-Boadu AK, Faunce WA, Fessler RG. Endoscopically assisted transoral-transpharyngeal approach to the craniocervical junction. *Neurosurgery*. 2002;51(5 Suppl):S60–6.
5. Kassam AB, Snyderman C, Gardner P, Carrau R, Spiro R. The expanded endonasal approach: a fully endoscopic transnasal approach and resection of the odontoid process: technical case report. *Neurosurgery*. 2005;57(1 Suppl):E213; discussion E.
6. Hadad G, Bassagasteguy L, Carrau RL, Mataza JC, Kassam A, Snyderman CH, et al. A novel reconstructive technique after endoscopic expanded endonasal approaches: vascular pedicle nasoseptal flap. *Laryngoscope*. 2006;116(10):1882–6.
7. Komotar RJ, Starke RM, Raper DM, Anand VK, Schwartz TH. The endoscope-assisted ventral approach compared with open microscope-assisted surgery for clival chordomas. *World Neurosurg*. 2011;76(3–4):318–27; discussion 259–62.
8. Liu JK, Patel J, Goldstein IM, Eloy JA. Endoscopic endonasal transclival transodontoid approach for ventral decompression of the craniocervical junction: operative technique and nuances. *Neurosurg Focus*. 2015;38(4):E17.
9. George B, Bresson D, Bouazza S, Froelich S, Mandonnet E, Hamdi S, et al. [Chordoma]. *Neuro-Chirurgie*. 2014;60(3):63–140.
10. Labidi M, Watanabe K, Bouazza S, Bresson D, Bernat AL, George B, et al. Clivus chordomas: a systematic review and meta-analysis of contemporary surgical management. *J Neurosurg Sci*. 2016;60(4):476–84.
11. Stacchiotti S, Sommer J. Building a global consensus approach to chordoma: a position paper from the medical and patient community. *Lancet Oncol*. 2015;16(2):e71–83.
12. Menezes AH. Clival and craniocervical junction chordomas. *World Neurosurg*. 2014;81(5–6):690–2.
13. Aldana PR, Naseri I, La Corte E. The naso-axial line: a new method of accurately predicting the inferior limit of the endoscopic endonasal approach to the craniocervical junction. *Neurosurgery*. 2012;71(2 Suppl Operative):ons308–14; discussion ons14.
14. Fernandez-Miranda JC, Morera VA, Snyderman CH, Gardner P. Endoscopic endonasal transclival approach to the jugular tubercle. *Neurosurgery*. 2012;71(1 Suppl Operative):146–58; discussion 58–9.
15. Funaki T, Matsushima T, Peris-Celda M, Valentine RJ, Joo W, Rhoton AL, Jr. Focal transnasal approach to the upper, middle, and lower clivus. *Neurosurgery*. 2013;73(2 Suppl Operative):ons155–90; discussion ons90–1.
16. Cebula H, Kurbanov A, Zimmer LA, Poczos P, Leach JL, De Battista JC, et al. Endoscopic, endonasal variability in the anatomy of the internal carotid artery. *World Neurosurg*. 2014;82(6):e759–64.
17. Labib MA, Prevedello DM, Carrau R, Kerr EE, Naudy C, Abou Al-Shaar H, et al. A road map to the internal carotid artery in expanded endoscopic endonasal approaches to the ventral cranial base. *Neurosurgery*. 2014;10(Suppl 3):448–71; discussion 71.
18. Cappabianca P, Cavallo LM, De Divitiis O, Esposito F. *Midline skull base surgery*. New York: Springer Science; 2016. xviii, 373 pages



19. Harvey RJ, Parmar P, Sacks R, Zanation AM. Endoscopic skull base reconstruction of large dural defects: a systematic review of published evidence. *Laryngoscope*. 2012;122(2):452–9.
20. Shriver MF, Kshetry VR, Sindwani R, Woodard T, Benzel EC, Recinos PF. Transoral and transnasal odontoidectomy complications: a systematic review and meta-analysis. *Clin Neurol Neurosurg*. 2016;148:121–9.
21. Perez-Orribo L, Little AS, Lefevre RD, Reyes PR, Newcomb AG, Prevedello DM, et al. Biomechanical evaluation of the craniovertebral junction after anterior unilateral condylectomy: implications for endoscopic endonasal approaches to the cranial base. *Neurosurgery*. 2013;72(6):1021–29; discussion 9–30.