Anterolateral and Extreme Lateral Approaches

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Kentaro Watanabe, Moujahed Labidi, Shunya Hanakita, Bernard George, and Sébastien Froelich

16.1 Introduction

Lesions of the cranio-vertebral junction (CVJ) are complex lesions to treat because of their deep location and complex surrounding anatomy composed of muscles, ligaments, joints, bony structures, cranial nerves, and critical vessels. They also frequently have an intricate morphology, involve the para-pharyngeal space, extend rostrocaudally, and from one side to the other. CVJ tumors can also extend both in the intradural and extradural compartments, often making closure and reconstruction challenging.

To help choose the optimal surgical route, many anatomically based classification schemes have been proposed for CVJ lesions. One such classification system is based on the location of the lesion in relation to the dura mater and divides CVJ lesions in three categories:

K. Watanabe · S. Hanakita · B. George · S. Froelich (✉)
Department of Neurosurgery, Hôpital Lariboisière, Assistance Pubique—Hôpitaux de Paris, Paris, France

Paris Diderot University, Paris, France
e-mail: Sebastien.froelich@aphp.fr, sebastien.froelich@lrb.aphp.fr

M. Labidi
Department of Neurosurgery, Hôpital Lariboisière, Assistance Pubique—Hôpitaux de Paris, Paris, France

Paris Diderot University, Paris, France

Division of Neurosurgery, Centre Hospitalier de l'Université de Montréal, Montréal, QC, Canada

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- *Intradural lesions*, such as lower clivus, foramen magnum, and C1-C2 meningiomas and schwannomas. Posterior circulation aneurysms can also be included in this category.
- *Extradural lesions*, which most often are tumors of bony origin from C1-C2, the occipital condyle, and lower clivus. Prototypical lesions are chordomas and chondrosarcomas, but also include plasmocytoma, lymphoma, secondary tumors, etc.
- *Mixed extra- and intradural lesions* of the CVJ, which are also most frequently chordomas and chondrosarcomas but also include glomus tumors and dumbbell tumors of the jugular and hypoglossal foramina.

The precise location of the tumor in the antero-posterior and lateral axes must also be taken into account in the surgical strategy: (1) anterior arch/clivus, (2) lateral mass of C1-C2/occipital condyle, and (3) posterior arch and occipital bone. In fact, many surgical approaches have been developed to reach these different anatomical regions and the surgeon must carefully select which is the most suitable route to be able to reach all tumor extensions. Among these surgical approaches, the retrocondylar and transcondylar posterolateral "far lateral," the extreme lateral transcondylar and the extreme lateral infrajugular transcondylar exposure (ELITE), with its anterolateral ELITE, and dorsolateral ELITE variations [1–15]. Each of these surgical approaches has specific indications, operative nuances, and limitations. In and around the foramen magnum, the surgeon must also be able to gain exposure and control of the jugular foramen, the vertebral artery, the occipital condyle, the dens, and the lower cranial nerves in the neck (Fig. 16.1).

In 1995, Bernard George et al. described the anterolateral approach (ALA) to access extradural and mixed intra- and extradural lesions of the anterior aspect of

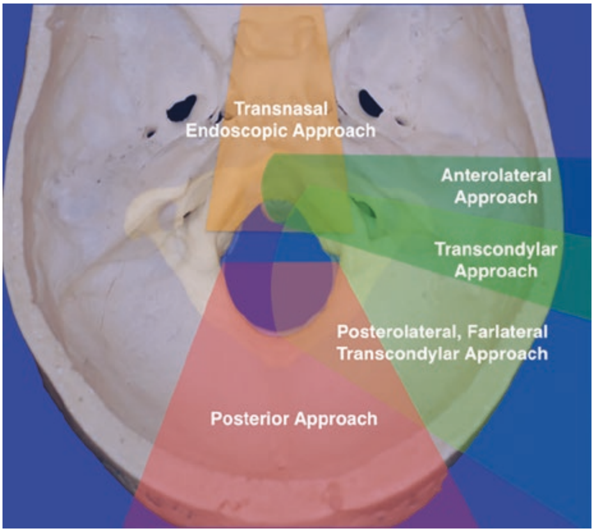

Fig. 16.1 Surgical corridors to the craniovertebral junction

the lower clivus and C1-C2 [3]. He also championed the general principles of vertebral artery management. In comparison to other lateral approaches to the CVJ, the ALA provides a very unique trajectory that is more “down-up” and from the high cervical to intracranial compartment. Conversely, the ELITE approaches have a trajectory that traverses the intracranial compartment first, before reaching the high cervical region [13, 16].

In this chapter, we summarize these different “lateral approaches” and focus particularly on the anterolateral approach. In addition, we describe extensions of the ALA, including classic skull base techniques such as vertebral artery transposition, but also endoscopic assistance. In fact, endoscopic visualization through transcervical exposures provides a wide range of possibilities in the CVJ, which we will discuss in detail in this chapter.

Through cadaveric dissections, we will first review the surgical anatomy relevant to the ALA and describe, step-by-step, the surgical technique to expose the CVJ through an ALA. Finally, clinical cases are presented in order to illustrate potential indications for the ALA and its different variations.

16.2 Anterolateral Approach

The anterolateral approach (ALA) was developed by Bernard George et al. as a novel surgical route for the anterior and lateral aspects of the CVJ. In fact, this region is difficult to reach though a posterior route without manipulation of neurological structures. Although it can be adequate in some cases, an anterior route to the lower CVJ, such as the submandibular approach, is usually limited by the mandibular bone and the salivary glands. The surgical trajectory of the ALA to the cranio-vertebral junction is from inferior to superior and from posterior to anterior. In addition to the cervical vertebrae, that are seen from a lateral perspective, the ALA allows exposure of the lower clivus and jugular foramen from below.

However, the first, second, and third segments of the vertebral artery (VA), located in the foramen transversarium of C1 to C6 vertebrae, is located in the center of the surgical field in an ALA. Therefore, careful management of the VA is an important issue in this area and has preoperative, operative, and postoperative consequences.

16.3 Differential Diagnosis of CVJ Lesions and Indications for ALA (cf. Table 16.1)

ALA is mainly indicated for lesions involving the occipital condyle, C0-C1 joint, lateral mass, and anterior arch of C1, odontoid process, lateral mass, and body of C2.

Table 16.2 summarizes the key characteristics of the different surgical approaches that can be discussed along with the ALA to treat lesions at the CVJ.

Table 161 The history of surgery of the lateral craniocervical junction and differences of the name of approach, a position, a skin incision, exposures of cervical area, vertebral translocation, and a target lesion, between the surgeons

Author (year)	Name of approach	Target lesion	Position	Skin incision	w/o high cervical exposure	w/o VA transposition	w/o mastoidectomy	Main corridor
Heros [4]	Far lateral	VA, VA-BA junction, proximal BA trunk, AVM of the inferolateral cerebellum	Park-bench	Vertical paramedian	–	–	–	Extreme lateral removal of the rim of the foramen magnum, C1 laminectomy
Yamamoto (1990) [17]	Unilateral suboccipital transcondylar	Intradural, anterior to lower brainstem, upper cervical cord, VA, basilar trunk	Sitting	Paramedian	+	–	–	Medial third, C1 laminectomy
Bertalanffy and Seeger (1991) [18]	Dorsolateral suboccipital transcondylar	Condyle, hypoglossal canal	Sitting	Vertical paramedian, straight, trans muscular		+	–	Condyle
George and Lot [3]	Anterolateral	VA, O-C condyle, anterior arch of C1, C2, C3 corpus body	Supine head rotation 30–45	Post-auricular linear incision, mastoid to cervical	+	+/–	–	C0, C1 condyle, C1 lateral mass
George (1997) [19]	Posterolateral	Posterior arch of C1, intradural CC junction	3/4 lateral position	Hockey stick	–	–	–	Retrosigmoid + C1, C2 posterior lamina
Fukushima (1996) [20]	Antero lateral ELITE[a]	Jugular foramen, mid-lower clivus, dumbbell-type schwannoma, Glomus meningioma	Supine head lateral	Post-auricular question mark	+	–	+	Infralabyrinthine transjugular approach with high cervical exposure, C1 laminectomy

Fukushima (1996) [20]	Dorsolateral ELITE[b]	Lower clivus, foramen magnum, VA_PICA complex aneurysm, V-B junction	Lateral	Lazy S	–	+/–	–	Infrajugular transcondylar transjugular tubercle
Sen and Sekhar [11]	Extreme lateral transcondylar	Foramen magnum, C1-C2 meningioma, ventral of brainstem	Modified Park-bench lateral	Lazy S	–	+	–/+	Retrosigmoid
Babu and Sekhar (1994) [21]	Extreme lateral transcondylar	Extradural tumor, intradural tumor	Modified Park-bench lateral	U shaped or C shaped	–	+	–/+	Intradural lesion; one-third to one half condyle resection, extradural lesion; transfacetal
Canalis et al. (1993) [22]	Lateral	Extradural tumor, intradural tumor	Supine and head rotated	Post-auricular to hyoid bone at midline	+	+	Partial	C1 laminectomy
Al-Mefty [1]	Transcondylar	Odontoid, extradural	Half-lateral decubitus	C shaped	+/–	+/–	Partial	OC-C1 condyle, odontoid
Matsushima (2010) [7]	Transcondylar fossa approach	Intradural lower clivus, foramen magnum lesion	Lateral	U shaped	–	+/–	–	Condyle fossa (C0 foramen magnum), infracondyle, transjugular tubercle

(continued)

Table 16.1 (continued)

Author (year)	Name of approach	Target lesion	Position	Skin incision	w/o high cervical exposure	w/o VA transposition	w/o mastoidectomy	Main corridor
Vallée (1993) [23]	Juxta-trans condylar approach	Tumor and aneurysm of the anterior or anterior-lateral of the foramen magnum	Lateral	Hockey stick	–	–	+	Condyle, suboccipital
S. Froelich	Endoscope assisted minimum, transcondylar	Medial jugular, clivus, anterior arch of C1, odontoid, contralateral condyle	Lateral	Small C shaped	–	+/–	–	Infrajugular bulb, transcondyle
S. Froelich	Endoscope assisted transmastoid	Medial jugular clivus, suprajugular foramen, mid-clivus, petrous apex, foramen lacerum, contralateral jugular foramen	Lateral	Small C shaped	+/–	–	+	Infralabyrinthine, suprajugular

AVM arteriovenous malformation, *BA* basilar artery, *PICA* posterior inferior cerebellar artery, *VA* vertebral artery
[a]Extreme lateral infralabyrinthine transjugular exposure with high cervical exposure
[b]Extreme lateral infrajugular transcondylar transtubercle exposure

Table 16.2 Surgical indications of the ALA, PLA

	Indications	Pathology
Anterolateral approach (ALA)	Extradural lesions Bone lesion C1-C2 Midline/lateral	– Chordomas – Myeloma – Metastasis – Tuberculosis – Primary bone tumors (chondroid tumor, sarcoma, fibrous dysplasia, osteoid osteoma)
Posterolateral approach	Intradural lesions Lower clivus/C2	– Meningiomas (foramen magnum, lower clivus) – Hemangioblastomas – Schwannomas (vestibular schwannoma, jugular foramen schwannoma, hypoglossal schwannoma) – Neurofibromas – Glomus tumors – Vascular pathology (VA, PICA, BA)
Extended endoscopic endonasal approach	Extra- and intradural lesions Midline Above C2 Soft tumors	– Chordomas – Primary bone tumors (chondroid tumor, sarcoma, myeloma) – Rheumatoid arthritis – Congenital bony abnormalities

ALA Anterolateral Approach, *BA* basilar artery, *PICA* posterior inferior cerebellar artery, *PLA* Posterior lateral approach, *VA* vertebral artery

16.4 Preoperative Considerations

A detailed study of the preoperative images should be done by an experienced multidisciplinary skull base team. An angio-CT of the vessels of the neck with bony reconstructions is mandatory. The head and cervical spine CT scan should be examined in detail to identify all areas of bony destruction of infiltration that need to be resected and/or reconstructed. All cases should also have an MRI of the head and cervical spine preoperatively, including contrast-enhanced sequences. In tumor cases, all extensions of the lesion to be resected should be delineated and recorded. Careful attention should also be given to extensions causing neurological compression, those that will not be accessible to adjuvant radiation therapy (i.e., close to the brainstem, bone infiltration, or near metallic implants, etc.).

The relationship of the lesion with the lower cranial nerves, namely the 9th, 10th, and 11th at the level of the jugular foramen and the 12th cranial nerve in its hypoglossal canal is another critical element to establish preoperatively. Their function should be assessed and documented, and in cases of severe preoperative dysfunction, a precautionary tracheostomy should be discussed in order to protect the airways during the postoperative period. When the lower cranial nerves function is impaired on one side and the contralateral nerves are involved or at risk during surgery, care should be taken to avoid catastrophic bilateral deficits and such a risk should be discussed frankly and in details with the patient and his/her family.

Preoperative assessment of CVJ instability with dynamic studies may be required in some tumor cases. Extent of condylar osteolysis, the presence of "dynamic" cervical pain and/or a hypoglossal palsy may be useful as clinical and radiological indicators of potential CVJ instability.

16.4.1 Vertebral Artery

Envisioning the precise localization of the VA is imperative at all times during an ALA. The VA is divided into four segments: (1) V1, or the "ostial" segment, is located between the subclavian artery and the *foramen transversarium* of C6, (2) V2, the "transversary segment" runs from C6 to C2 in the *foramen transversarium*, (3) V3 or the "suboccipital" segment extends from the *foramen transversarium* of C2 to the point of entry of the VA in the intradural compartment, and (4) V4 is the "intradural" segment [14]. The V3 segment can be further divided into a vertical segment between the transverse foramen of C2 and the transverse foramen of C1 and a horizontal segment along the posterior arch of C1.

The VA is surrounded by a dense venous plexus, which should be kept intact and not be disrupted when manipulating the VA, in order to avoid profuse venous bleeding.

Moreover, anatomic variations of the VA are frequent, including loops and anomalous locations. Elderly patients are particularly prone to vascular ectopia, atherosclerosis, and calcifications. Bone anatomical variations such as arcuate foramen, occipitalization of the atlas, and defect of the posterior arch of C1, defect of the transverse foramen of C1 can also occur leading to surgeon disorientation and VA injury [24–26].

One should also be aware that with the head rotation that is needed for ALA, the vertical segment of the V3 becomes horizontal and can be identified immediately below the posterior arch of C1 (Fig. 16.2).

In other cases, there can be an extradural origin of the posterior inferior cerebellar artery (PICA) [24, 27]. It is thus critical that anatomical variations be recognized preoperatively on a CTA.

When the tumor involves the vertebral artery, it is important to clarify if and how the VA can be sacrificed. In some pathology, resection of an invaded VA may be required for oncological control of the tumor while in other tumors, adjuvant therapy is sufficient to ensure long-term control of residual tumor. Ideally, this should be discussed in multidisciplinary tumor boards. In cases where VA ligature/resection is considered, a balloon test occlusion (BTO) should be performed preoperatively. If the patient fails the BTO, a revascularization procedure may be required before the actual resection can take place safely.

16.5 Surgical Anatomy and Technique

16.5.1 Positioning

The patient is placed supine and the head rotated laterally, approximately 30–45° to the contralateral side (Fig. 16.2a–d). Placing the head in slight extension is

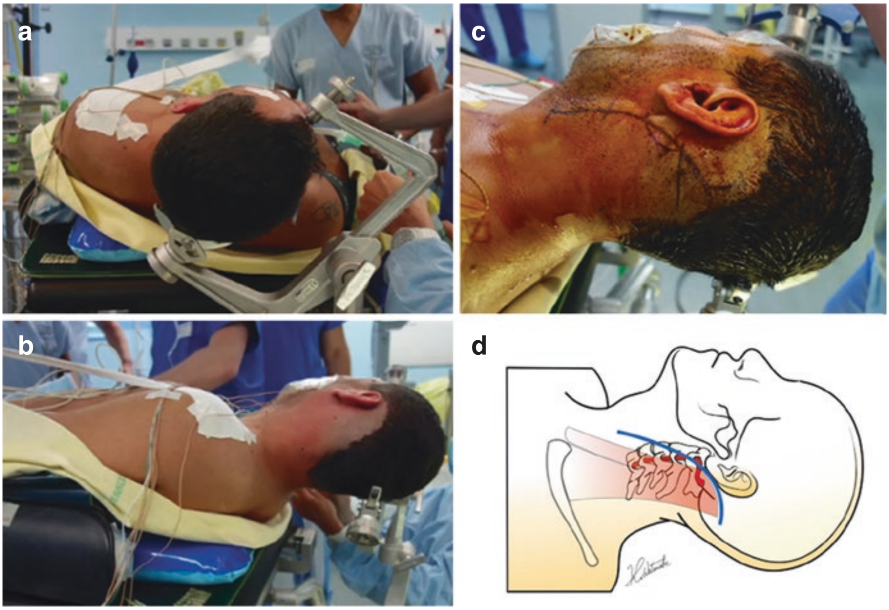

Fig. 16.2 Surgical positioning in an anterolateral approach. (**a**) The patient is placed supine and the head is rotated laterally, approximately 30–45° to the contralateral side. A Mayfield head holder can be used in most cases (as shown in the figure), but a "horseshoe" headrest can allow neutral repositioning of the head during cases when fixation or vertebral reconstruction are planned. (**b**) A wide area around the planned skin incision should be prepped to have a large working space. The head should not be rotated too much. (**c**) Skin incision in an anterolateral approach. It is made along the upper third of the anterior border of the sternocleidomastoid muscle and is curved at the level of the mastoid process (skin markings) and the occipital crest

important to disengage the angle of the mandible. A horseshoe headrest is preferred since it allows modification of the position of the head if necessary. More importantly, if the need for osteosynthesis or vertebral reconstruction arises during the case, the head can then be placed in a neutral position to do so.

The shoulders should be as flat as possible and should not impede the surgeon. Rotation of the head can be adjusted depending on the location of the lesion and its extensions; with increasing rotation, the anterior arch of C1 becomes progressively hidden by the transverse process of C1 and the vertebral artery (Fig. 16.3).

16.5.2 Neurophysiological Monitoring and Surgical Adjuncts

Electromyographic (EMG) monitoring of the 7th, 9th, 10th, 11th, and 12th nerves, motor and sensory evoked potentials are done in all cases of ALA. Direct stimulation with an EMG probe can be useful in cranial nerve identification and preservation (especially 11th cranial nerve). Neurophysiological monitoring with somatosensory evoked potentials (SSEPs) and motor evoked potentials (MEPs) also

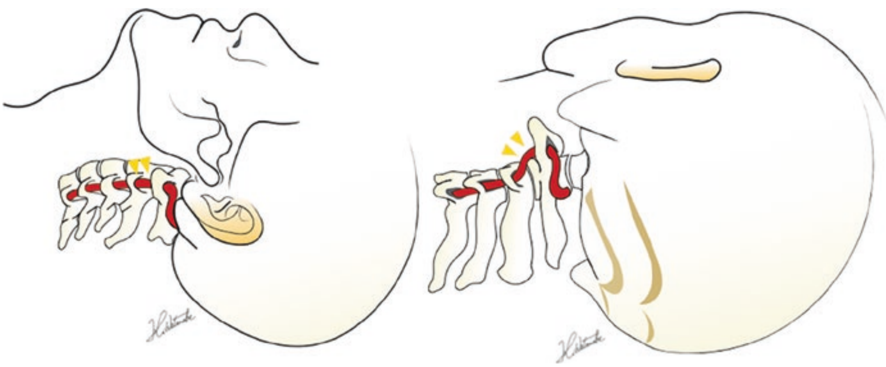

Fig. 16.3 Rotation of the head can be adjusted depending on the location of the lesion and its extensions; With increasing rotation, the anterior arch of C1 becomes progressively hidden by the transverse process of C1. More importantly, the vertebral artery's trajectory is altered by rotation of the head as the vertical portion of V3 is "horizontalized"

has a pivotal role during the surgical positioning of unstable high cervical lesions and during tumor resection in case of brainstem or high cervical medullary compression.

Neuronavigation is not used routinely since its precision in the CVJ, especially through an ALA, is usually inadequate. Electromagnetic neuronavigation and intra-operative imaging might be used in select cases. We routinely use the micro-Doppler probe in all ALA cases.

16.5.3 Skin Incision

The skin incision is made along the upper third of the anterior border of the sterno-cleidomastoid (SCM) muscle and is curved at the level of the mastoid process and the occipital crest (Fig. 16.3). The anterior border of the SCM can be approximated by a line connecting the manubrium and the mastoid tip. The height of the incision can be adapted to the surgical goals and strategy. For instance, when a mastoidec-tomy is planned, the incision needs to reach the level of the transverse sinus. The inferior border of the incision also depends on the pathology at hand, but 5–6 cm below from the mastoid tip on the anterior border of the sternocleidomastoid muscle is usually adequate for CVJ exposures.

16.5.4 High Cervical Dissection and Exposure of the Vertebral Artery

16.5.4.1 Dissection Between the SCM and Internal Jugular Vein

After the skin and hypodermis are incised, the first layer that is encountered is the platysma, which is dissected and incised parallel to the skin incision. The SCM is then exposed and its medial border followed. The great auricular nerve can be dissected on the surface of the SCM (Fig. 16.4a). This nerve can be used for nerve reconstruction in case of cranial nerve injury or sutured back at the end of the procedure. The cervical fascia is then opened along the medial aspect of the SCM muscle and the internal jugular vein (IJV) is identified (Fig. 16.4b, c). The facial vein is usually encountered and can be ligated safely. The mastoid insertion of the SCM is then cut and the insertion of the splenius capitis muscle and longissimus muscle are detached from the mastoid process and occipital bone. These muscles are translocated posteriorly (Fig. 16.4d, e).

16.5.4.2 Identification of the Posterior Edge of the Digastric Muscle

The IJV is dissected and followed distally up to the posterior border of the digastric muscle. The digastric muscle is found under the SCM, and can be easily identified and traced anteriorly starting from its groove posterior to the mastoid tip. During this dissection, the occipital artery (OA) can be found coming from under the digastric muscle. The OA can be ligated or preserved to serve as a donor vessel if the need for revascularization arises.

16.5.4.3 Detachment and Mobilization of the Digastric Muscle

In order to further expose the jugular foramen and lower cranial nerve that exit from the foramen, it is necessary to detach the digastric muscle from the digastric groove of the mastoid process and to mobilize it inferiorly (Fig. 16.4f). The facial nerve exits from the stylomastoid foramen and runs medially to the deep fascia of the digastric muscle toward the inferior aspect of the parotid gland. In this segment, the facial nerve gives off a branch to the digastric muscle, about 1 cm below the mastoid tip. Although the facial nerve branch is usually covered with fat tissue, manipulation, partial resection, and/or retraction of the digastric muscle should be done carefully so as not to injure the facial nerve. Thus, when the digastric muscle is sectioned, the anterior aponeurosis of the muscle should be preserved to protect the facial nerve.

A common mechanism of injury of the facial nerve is prolonged and overly aggressive retraction with autostatic retractors that are positioned too high immediately below the tip of the mastoid.

16.5.4.4 Identification of the Accessory Nerve and Dissection of the Fat Pad (Fig. 16.4d, e)

The C1 lateral process, which can be easily identified by palpation, is found approximately 1 cm below the tip of the mastoid. The C1 lateral process is a very important landmark for the vertebral artery (VA) and the accessory nerve (XIth). In most patients, the XIth can be found 0.5–1 cm below the transverse process of C1. From there, the nerve runs more or less obliquely superomedially to infero-laterally in direction of the medial border of the SCM muscle at the C3–C4 level. The carotid fat pad, located in the triangle formed by the posterior edge of the digastric muscle, the splenius muscle, and internal jugular vein encloses the XIth. The XIth is

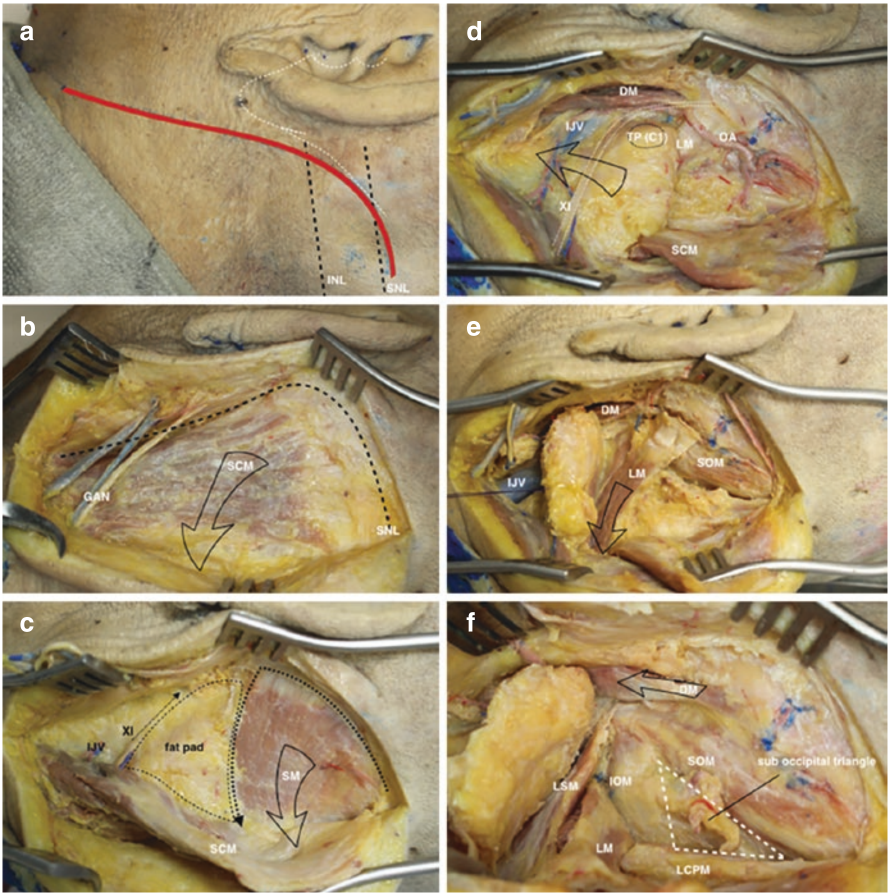

Fig. 16.4 (**a**) The skin incision is made along the upper third of the anterior border of the sternocleidomastoid (SCM) muscle and is curved at the level of the mastoid process and the occipital crest. (**b**) The Greater auricular nerve can be seen running above the SCM. The SCM is detached from the mastoid and transposed inferiorly. *GAN* greater auricular nerve, *SCM* sternocleidomastoid muscle. (**c**) Under the SCM, the splenius muscle and a fat pad are exposed. The accessory nerve can be identified in the fat pad inferiorly. *IJV* internal jugular vein, *XI* accessory nerve. (**d**) After transposition of the splenius muscle posteriorly, the fat pad can also be detached from the surrounding tissues and can be transposed inferiorly and kept as a protective layer for the accessory nerve. *DM* digastric muscle, *IJV* internal jugular vein, *OA* occipital artery, *LM* longissimus muscle, *TP* transvers process, *XI* accessory nerve. (**e**) Under the fat pad, the longissimus muscle can be exposed and detached from the mastoid inferiorly. The superior oblique muscle is exposed. *DM* digastric muscle, *IJV* internal jugular vein, *LM* longissimus muscle, *SOM* superior oblique muscle. (**f**) The suboccipital triangle, defined by the superior oblique muscle, the inferior oblique muscle, and the rectus capitis posterior major muscle. *DM* digastric muscle, *IOM* superior oblique muscle, *LM* longissimus muscle, *LSM* Levator scapulae muscle, *SOM* superior oblique muscle

superficial in this fat pad and can be readily detected with electric stimulation. Once the XIth nerve is identified, the fat pad can then be detached superiorly and mobilized downward from the digastric, splenius muscles and from the dense fibro-fatty tissue covering the suboccipital triangle. It is then used as a natural protection for the retraction of the XIth nerve inferiorly [28].

16.5.4.5 Identification of the Suboccipital Triangle (Fig. 16.4f)

In addition to the transverse process, the suboccipital triangle is also an important landmark for identification of the VA. This triangle is defined by the superior oblique muscle, the inferior oblique muscle, and the rectus capitis posterior major and is covered by a layer of dense fibro-fatty tissue. It is located beneath the semispinalis capitis.

At the level of the C1 posterior lamina, the vertebral artery as well as the vertebral venous plexus and C1 nerve root can be found in the center of this triangle. Muscular branches often arise from the horizontal segment of the VA in this area. Rarely, a PICA with an extradural origin may originate from the V3 segment on its horizontal portion, just outside the dura or further laterally above the transverse foramen of C1. The incidence of an extradural origin of the PICA is between 5 and 20% (George). In this configuration, the PICA courses parallel to the VA and the C1 nerve root extradurally.

16.5.4.6 Exposure of the Transverse Process (TP) of C1

To fully expose the transverse process of C1 and easily identify the foramen transversarium at this level; the muscles inserted on the TP of C1 are detached. Five muscles insert on the TP of C1: the rectus capitis lateralis, the superior oblique, the inferior oblique, the splenius cervicalis, and the levator scapulae muscles (Fig. 16.5a, b). The muscle insertion on the TP of C1 are progressively coagulated and sectioned until the posterior aspect of the TP of C1 is identified and further exposed using subperiosteal dissection. The opening of the transverse foramen is identified with a dissector along the superior and inferior aspect of the TP of C1, in this area, large venous plexuses are found in the retrocondylar fossa, around the vertebral artery and between the TP of C1 and the lateral mass of C2. These venous plexuses should be left intact as much as possible to avoid profuse bleeding. Coagulation is often ineffective while injectable hemostatic agents are usually sufficient in controlling such venous bleeding (Fig. 16.5d–f).

16.5.4.7 VA Exposure

Safe tumor removal and adequate access requires mobilization, translocation, or at least identification of the VA above and below the transverse foramen of C1 (V2 and V3 segments) (Fig. 16.5c). The superior surface of the posterior arch of C1 has an osseous groove in which the VA is located, the *sulcus arteriosus*. The safest way to identify the VA is to follow laterally the posterior arch of C1 from the midline. The sulcus arteriosus, along the superior surface of the posterior arch of C1, is exposed subperiostally, from medial to lateral until the superior opening of the transverse foramen of C1 is identified. It is imperative that this dissection be done

Fig. 16.5 (**a**) C1 transverse process is exposed and the rectus capitis lateralis muscle is exposed below the mastoid. *IOM* superior oblique muscle, *LM* longissimus muscle, *LSM* Levator scapulae muscle, *SOM* superior oblique muscle. (**b**) The muscles which are attached to the C1 transverse process can be coagulated and detached. *IOM* superior oblique muscle, *LM* longissimus muscle, *LSM* levator scapulae muscle, *SOM* superior oblique muscle, *RCLM* rectus capitis lateralis muscle. (**c**) After transposition of the cervical muscles and the transvers process of C1 has been denuded, the vertebral artery (V3) can be seen in the C1 arterial groove and between the C1 and C2. *TP* transverse process, *IJV* internal jugular vein. (**d**) The transverse foramen is opened, uncovering this whole 3^{d} segment of the vertebral artery. *IOM* superior oblique muscle, *LM* longissimus muscle, *LSM* levator scapulae muscle, *SOM* superior oblique muscle, *VA* vertebral artery. (**e**) The vertebral artery is transposed posteriorly and medially from the transverse foramen. *LSM* levator scapulae muscle, *VA* vertebral artery. (**f**) The transverse process is drilled and lateral mass is exposed. *LM* lateral mass, *VA* vertebral artery

subperiosteally. In fact, the periosteum acts as a protective layer for the venous plexus around the VA. Then, the TP of C1 is removed (Fig. 16.5c, d). The tip can be first removed with a rongeur. Once the cancellous bone of the TP is exposed, we favor the use of a high-speed diamond drill in order to progressively unroof the transverse foramen of C1. The last shell of cortical bone that form the posterior margin of the foramen is then removed with a kerrison rongeur. Once the transverse foramen of C1 is completely open, the third segment of the VA can be separated from the foramen and fully mobilized. The vertebral artery can also be followed downward toward the transverse foramen of C2. At this level, the C2 nerve root is identified. Once the transverse foramen of C2 is identified, the foramen can be opened, and the TP of C2 removed to allow further mobilization of the VA (Fig. 16.5e, f).

16.5.4.8 Rectus Capitis Lateralis Muscle (RCLM) (Fig. 16.5a, b)

The rectus capitis lateralis muscle (RCLM) is one of the key muscles to access the anterior aspect of the cranio-vertebral junction. The RCLM is a short muscle attached to the upper surface of the TP of C1 and to the jugular process located between the mastoid process and the occipital condyle. To access the cranio-vertebral segment of the IX, X, XI, XII nerves and the IJV or the anterior part of C1, the odontoid process, and the lower clivus, both the TP of C1 and the RCLM should be removed. If a tumor extends to the high cervical region, in the case of a dumbbell-type jugular foramen lesion or a lower clivus and cervical chordoma, removing the RCLM is usually required to gain enough space to access the anterior aspect of the CVJ and benefit from the look up view to the jugular foramen and clivus that the ALA can provide.

16.5.5 Variations and Extensions

16.5.5.1 Transposition of the VA

If the VA is not already occluded by the tumor and when the condyle, the lateral mass of C1, odontoid process or the clivus is invaded by tumor, transposition of the VA is often necessary to fully expose the lesion. In case of a soft chordoma, full transposition may be avoided. After identifying the horizontal segment of the vertebral artery along the sulcus arteriosus, the TP of C1 is removed and the transverse foramen of C1 is opened. The V3 segment is then displaced posteriorly and out of the transverse foramen of C1, freeing a corridor to the lateral mass of C1 and beyond. The periosteal sheath and vertebral plexus around the VA should be kept intact to protect the VA, reduce venous bleeding, and minimize the risk of dissection. When additional mobility is needed, the transverse foramen of C2 can also be opened, liberating completely the suboccipital segment of the VA.

After translocation of the VA and exposure of the lateral mass of C1, the anterior arch of C1 is followed in direction of the midline and even to the contralateral side of the anterior arch (Fig. 16.6a). Subsequent resection of the tumor infiltrating the lateral mass of C1, the odontoid process and surrounding ligaments (alar, transverse and apical) and the contralateral mass of C1 can be performed (Fig. 16.6b, c). Care must be taken to preserve the contralateral vertebral artery, especially if the ipsilateral vertebral artery is occluded by the tumor or has been already been sacrificed during the surgery. The use of a Doppler probe is mandatory to identify the contralateral VA.

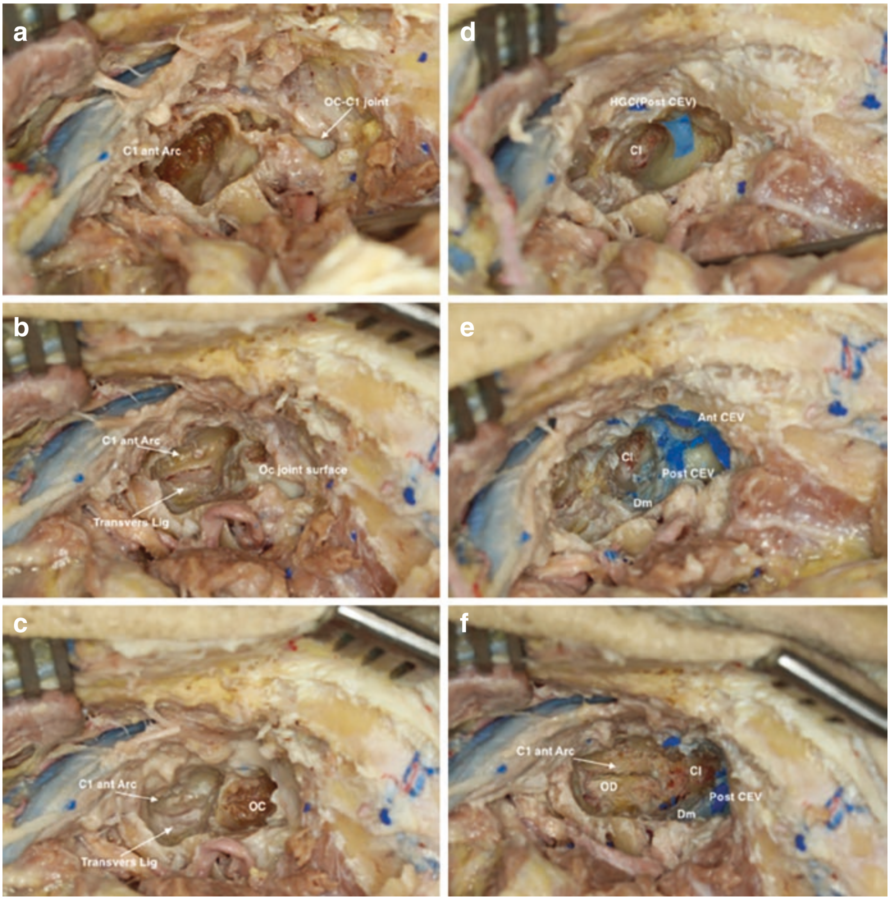

Fig. 16.6 (**a**) After drilling of the C1 lateral mass, the anterior arch of C1 can be accessed. *C1 ant Arc* C1 anterior arch. (**b**) The C1 anterior arch is drilled until the midline, the transverse ligament of the odontoid process is exposed. *Transverse lig* transverse ligament. (**c**) The occipital condyle can be also drilled to gain an upper view to the lower clivus. *C1 ant Arc* C1 anterior arch, *OC* occipital condyle, *Transvers lig* transverse ligament. (**d**) The hypoglossal canal with the posterior condyle emissary vein can be seen in the condyle. Anterior to the hypoglossal canal, an area of cancellous bone is found. This finding indicates entry into the lower aspect of the clivus. *Cl* clivus, *HGC* hypoglossal canal, *Post CEV* posterior condyle emissary vein. (**e**) The anterior condyle emissary vein and the posterior condyle emissary vein can be skeletonized during condylar drilling. These veins connect to the occipital venous plexus. *Cl* clivus, *HGC* hypoglossal canal, *Ant CEV* anterior condyle emissary vein, *Post CEV* posterior condyle emissary vein. (**f**) The view obtained after drilling the anterior arch of C1 and condyle. The odontoid process and dura mater of the spine are exposed. *C1 ant Arc* C1 anterior arch, *Cl* clivus, *HGC* hypoglossal canal, *Dm* dura mater, *OD* odontoid process, *Post CEV* posterior condyle emissary vein

16.5.5.2 Condylar Resection

In case of a tumor extending in the condyle and the lower clivus, such as chordomas, chondroid tumors, myeloma, hypoglossal schwannoma, etc. a resection of the condyle may become necessary. To gain adequate exposure of these lesions, the inferior part of the sigmoid sinus and the jugular bulb is skeletonized. The retrocondylar fossa is exposed and the posterior condylar emissary vein are identified. After partial condylectomy, the anterior condylar emissary vein can also be seen (Fig. 16.6d, e). It runs with the hypoglossal nerve in the hypoglossal canal and is exposed with the inferior aspect of the sigmoid sinus and jugular bulb (Fig. 16.6e, f). This is the combination of an anterolateral approach and a far lateral transcondylar approach.

It is important to limit bony resection if it is not necessary for surgical exposure or from an oncological standpoint. However, oftentimes the tumor has already compromised the structural integrity of the C0-C1 joint. When involvement of the condyle is superior to 75%, occipitocervical fusion is usually necessary, although some reconstruction strategies can obviate the need for rigid fixation. Limiting the drilling to the posterolateral third of the condyle also reduces the risk of injury to the hypoglossal canal and nerve, which is located in the anteromedial aspect of the condyle.

To access the anterior arch of C1 or the odontoid process, opening of the C0-C1 joint with condylar and lateral mass removal provide an adequate trajectory. Slight downward mobilization of the horizontal segment of the V3 segment of the VA is needed to expose the lateral mass of C1. Rather than a complete translocation of the VA and resection of the rectus capitis lateralis muscle, this can be an alternative strategy to reach the anterior aspect of the CVJ.

16.5.5.3 Inferior Extension to the C2-4 Vertebrae

When the target lesion extends inferiorly to C2-C3, exposure of the V2 segment of the VA is necessary [14]. The C2 lateral process and the longus colli and longus capitis muscles can be exposed and removed to expose the VA and gain access to the body of C2 and the lower cervical vertebrae. In this situation, care must be taken to avoid injuring the sympathetic chain and the superior cervical ganglion, which run under the prevertebral fascia over the longus coli muscle. The vagus nerve gives off the superior and recurrent laryngeal nerves. These nerves run medially to the carotid-jugular sheath and, contrarily to an anterior approach, are not at risk of injury. However, care must be taken not to compress the vagal nerve in order to avoid laryngeal nerve dysfunction.

16.5.5.4 Intradural Extension, Combined Extradural, and Intradural Approach

In cases when the tumor originates intradurally, the far lateral transcondylar approach is usually preferred as a larger surface of posterior fossa dura can be exposed and better neurovascular control can be insured than through an ALA. When there is extradural extension of a mostly intradural tumor, for example a meningioma invading the clival bone, these extensions can often be reached transdurally though the intradural exposure provided by the far lateral transcondylar or posterolateral approach. Similarly, and as it is often the case for chordomas, intradural tumor extensions of mostly extradural tumors can usually be resected through the ALA extradural exposure, after tumor resection has provided the space and corridor to do so.

16.5.5.5 Endoscope Assistance Through an ALA

In addition to classic skull base techniques such as mastoidectomy, unroofing the hypoglossal canal, or transposition of the vertebral artery, the use of endoscopic assistance has also proven to be an invaluable tool to increase the exposure provided by the ALA. The endoscope increases both illumination and visualization in these deep locations. It should be used as a tool to navigate and operate in the depths of the triangles defined by the lower cranial nerves and vertebral artery. When using the endoscope through these "deep keyholes," further tumor resection can be accomplished in the lower clivus more anteriorly in the prevertebral retropharyngeal space, medially and inferiorly in the periodontoid region and, controlaterally in the opposite lateral mass of C1, in and around the odontoid process and around the contralateral occipital condyle.

Through the condylar corridor, and with careful protection of the hypoglossal nerve, endoscopic assistance can provide visualization of tumor extensions higher up into the middle and superior third of the clivus, toward the petrous apex and sphenoid sinus. With the cervical muscles retracted inferiorly and the high cervical dissection already providing the look up trajectory, exposure can indeed reach the level of the sphenoid sinus. When the tumor is soft and easily aspirated, the resection cavity becomes an additional corridor to deepen the exposure.

16.6 Complication Avoidance and Management

The most frequent complications encountered during and after and ALA are cranial nerve palsy, vertebral artery injury, and cervical hematoma. As in all cervical surgery, careful hemostasis is mandatory and can prevent the occurrence of a potentially life-threatening hematoma. The "coagulate and cut" technique helps providing a dry surgical field and probably reduces the occurrence of a postoperative hematoma. The use of a subcutaneous drain can also be considered depending on the situation.

In case of intraoperative injury to the VA, and when a BTO has not been obtained before the surgery or has been failed, the objective should be to preserve flow and avoid emboli. A primary repair of the VA can be attempted when the arterial wall defect is small. When the risk of intraoperative rupture is high, i.e., after radiation therapy or when there is tumor encasement, the arm can be draped to be prepared for radial artery graft harvest. The radial artery is an ideal donor in terms of size match with the VA and long-term patency. Otherwise, the occipital artery can serve as a donor vessel when it is of adequate size and has been preserved while performing the approach [29].

16.7 Clinical Cases

Case Illustration 1 (Figs. 16.8 and 16.9)
A 72-year-old male was referred to our clinic after multiple previous operations for a cervical chordoma. The patient initially presented an acute tetraparesis secondary to a C2-C3 lesion. The patient underwent in another center emergency laminectomy but this posterior approach did not allow exposure of the tumor and a subsequent anterior surgery for tumor biopsy was done.

The patient improved neurologically after the first surgery but presented unrelenting cervical pain that required constant immobilization with a Minerva orthosis. On the MRI, a lesion centered on the vertebral body of C3 with an extradural extension behind the inferior half of the body of C2 was found. Its characteristics on T1 and T2-weighted images were concordant with chordoma (Fig. 16.7a–f).

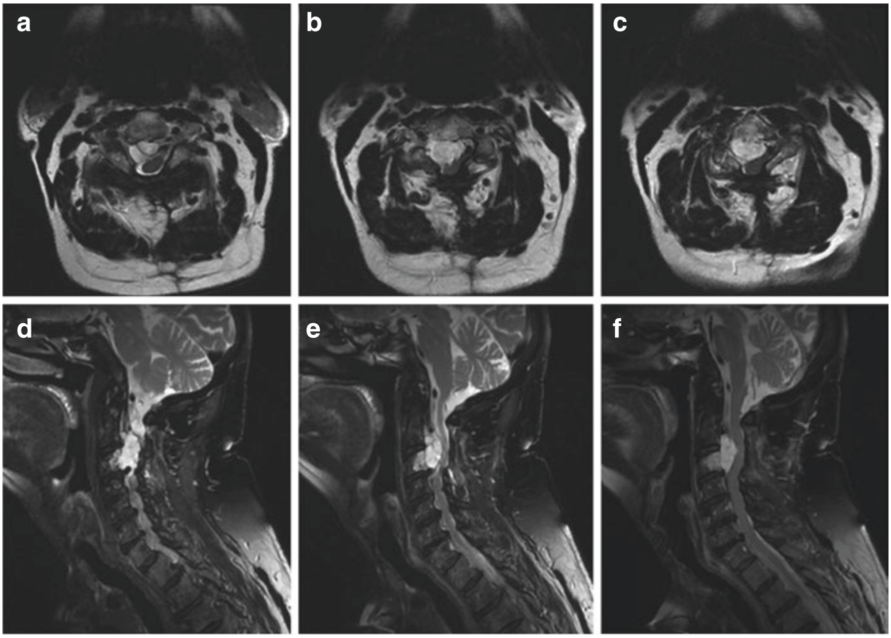

Fig. 16.7 T2-weighted MR images (**a**–**c**; axial and **d**–**f**; sagittal) showing a lesion at the posterior aspect of the C2-C3 vertebral bodies and causing compression on the spinal cord

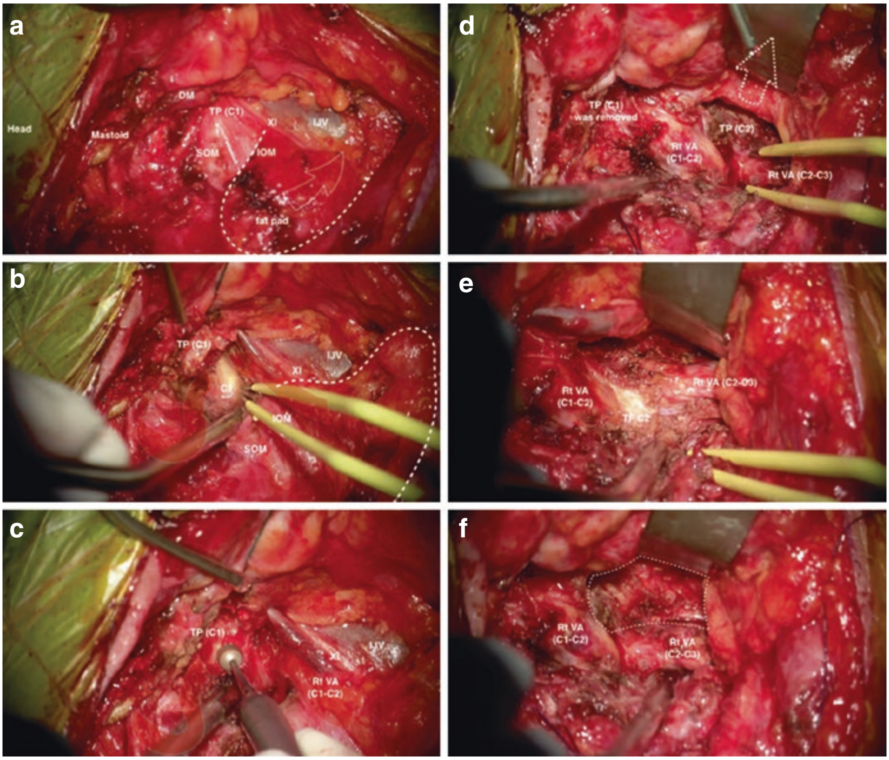

Fig. 16.8 (**a**) The fat pad, and the accessary nerve, inferior jugular vein, transverse process are exposed. The accessory nerve is protected with the fat pad. *DM* digastric muscle, *IOM* inferior oblique muscle, *IJV* internal jugular vein, *SOM* superior oblique muscle, *TP* transverse process, *XI* accessory nerve. (**b**) The fat pad is translocated inferiorly with protection of the accessory nerve. The C1 posterior arch is exposed by detaching the superior oblique and inferior oblique muscles from the C1 transverse process. *IOM* inferior oblique muscle, *IJV* internal jugular vein, *SOM* superior oblique muscle, *TP* transverse process, *XI* accessory nerve. (**c**) The C1 transverse process is drilled and the transverse foramen opened, thus uncovering V3. *IJV* internal jugular vein, *Rt. VA* right vertebral artery, *XI* accessory nerve. (**d**) C2 transverse process is also removed, allowing mobilization of the segment of the vertebral artery between its exit from C3 transverse foramen to its intradural entry. The internal jugular vein is retracted anteriorly, opening a corridor to the anterior aspect of the C2-C3 vertebral bodies. *Rt. VA* right vertebral artery, *TP* transverse process, (**e**) The transverse foramen of C2 is opened, exposing the vertebral artery from C1 to C3. *TF* transverse foramen. (**f**) The surgical corridor to the anterior aspect of the C2-C3 vertebral bodies. *Rt. VA* right vertebral artery

Gross total resection of the lesion was accomplished through an anterolateral approach. Considering that the vertebral bodies of C2 and C3 were only partially resected (Figs. 16.8 and 16.9), neither vertebral body reconstruction nor posterior cervical fixation was required. Clinically, the cervical pain remitted and the patient did not present any neurological deficit. He underwent adjuvant proton beam therapy.

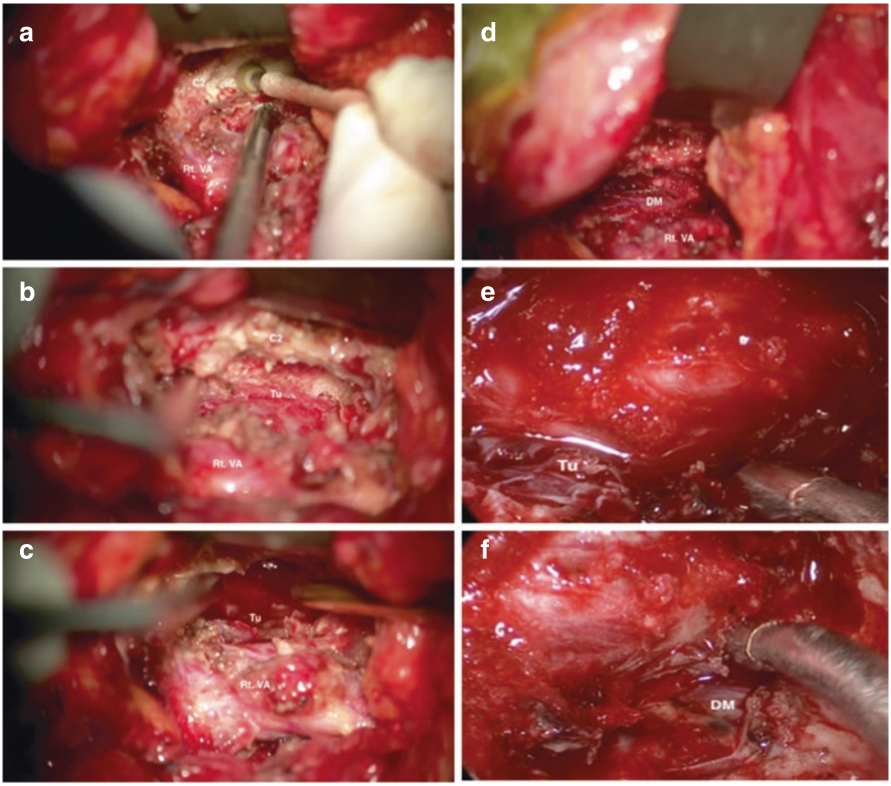

Fig. 16.9 (**a**) The posterior past of the vertebral body of C2 is drilled to expose the tumor. *Rt. VA* right vertebral artery. (**b**) The tumor is seen between the C2 vertebral body and the vertebral artery. *Rt. VA* right vertebral artery, *Tu* tumor. (**c**) An area of soft tumor can be seen in the vertebral body. *Rt. VA* right vertebral artery, *Tu* tumor. (**d**) After resection of the tumor, the dura mater of the cervical spine is seen. *DM* dura mater. (**e**) Endoscopic view in the anterolateral corridor. The border between the tumor and normal structures can be inspected precisely. *Tu* tumor. (**f**) After removing the tumor and fibrous tissue, the clean dura mater can be seen. *DM* dura mater

Case Illustration 2 (Figs. 16.10 and 16.11)
A 41-year-old man initially presented with headaches. On imaging, a tumor was found in the left petrous apex. The patient underwent surgical resection through a left anterior petrosectomy and was diagnosed with chondrosarcoma. Four years later, he was referred to us with hoarseness, dysphagia, and partial deviation of the tongue. The tumor was found to have grown and was causing mass effect on the jugular foramen. It was extending to level of C2 inferiorly and to the sphenoid sinus superiorly. We performed anterolateral and posterolateral transmastoid combined approach with endoscopic-assisted resection of this large lesion. Care was taken to preserve a barrier between the extradural and intradural compartment of the lesion. Two corridors were used to access the tumor (multiportal surgery): (1) the high cervical anterolateral approach, to benefit from the look up view to the lower clivus and medial aspect of

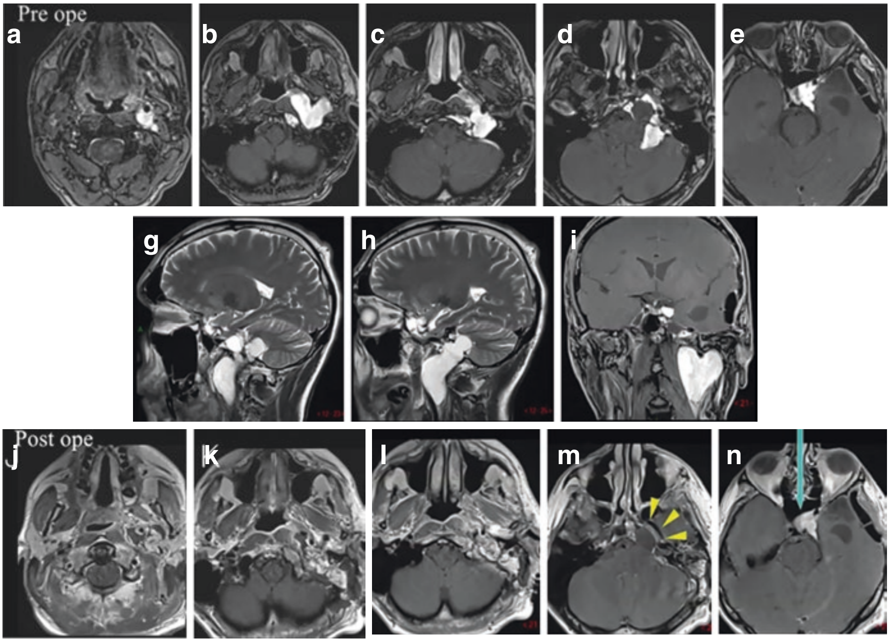

Fig. 16.10 The MRI shows a lesion in the area of the jugular foramen and extending from C2 to the sphenoid sinus. The tumor engulfs the internal carotid artery and extends into the intracranial compartment through the jugular foramen. (**a**–**e**) Preoperative gadolinium enhanced T1weighted axial images show the tumor engulf the carotid artery and jugular foramen. (**g**–**i**) Preoperative MRI T2 weighted sagital images show the tumor located from the C2 level to the sphenoid sinus. (**j**–**n**) Postoperative MRI Gadolinium enhanced T1 image show the tumor was removed except the sphenoid sinus lesion. The part of the tumor that was located in the mastoid area was partly resected during the previous surgery. Postoperative MRI image shows a small residual tumor in the sphenoid sinus

the jugular foramen, and (2) transmastoid presigmoid, suprajugular bulb look down view on the medial jugular foramen. The transmastoid corridor also allowed better visualization of the lesions extending toward the petrous apex. A small residual tumor that was left in the sphenoid was subsequently resected though an endoscopic endonasal approach. Clinically, the patient did not present any new neurological deficit.

16.8 Summary

The anterolateral approach grants a unique surgical trajectory to the cranio-vertebral junction that is in an inferior to superior and posterior to anterior direction. In addition to the cervical vertebrae, including C1 and C2 that are seen from a lateral perspective, the ALA allows exposure of the lower clivus and jugular foramen from below. Detailed knowledge of the 3D surgical anatomy, especially of the vertebral artery, is paramount for safe dissection and exposure through an ALA. In our practice, it is most often used to resect chordomas and other bony lesions of the CVJ. Endoscopic assistance as a surgical tool is an important adjunction that can enhance the exposure provided by the ALA in order to reach deep tumor extensions.

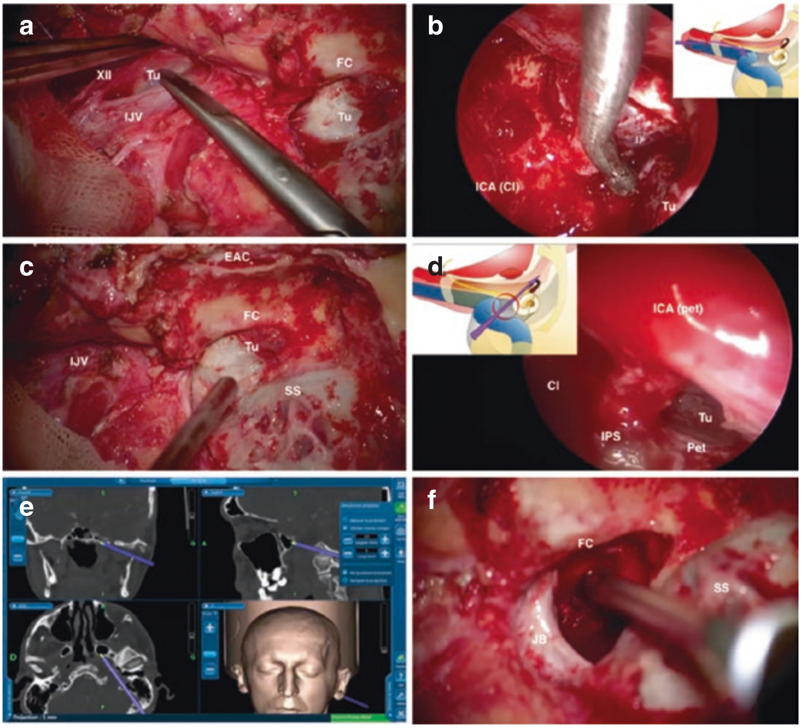

Fig. 16.11 (**a**) After an anterolateral approach and dissection, the internal jugular vein and hypoglossal nerve are seen. The tumor is exposed between the internal jugular vein and hypoglossal nerve. (**b**) Endoscopic assisted tumor removal is performed through the high cervical corridor, in the space between the internal jugular vein and hypoglossal nerve. The endoscope improved visualization of the tumor, which was located medial to the jugular foramen. (**c**) The fallopian canal and sigmoid sinus are exposed after mastoidectomy. The tumor can be seen between the fallopian canal and sigmoid sinus. (**d**) Endoscopic-assisted tumor removal is performed through the retrofacial presigmoid, suprajugular corridor. The inferior petrosal sinus is seen between the petrous bone and clivus. Through this corridor, the petrous segment of the internal carotid artery is identified. (**e**, **f**) The neuronavigation indicates the area of the petrous apex, confirming that the tumor was totally removed in this location

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