A Contemporary Clinico-Anatomical Guide to Craniovertebral Junction Surgery

Alexander Spiessberger1✉ Basil Gruter2 Giyarpuram Prashant3 Joshua Haegler4 Mark Eisenberg3
Aaron A. Cohen-Gadol5 Amir R. Dehdashti1

1 North Shore University Hospital, Manhasset, New York, United States
2 Department of Neurosurgery, University Hospital Zurich, Zurich, Switzerland
3 Department of Neurosurgery, North Shore University Hospital, Manhasset, New York, United States
4 Department of Neurosurgery, Kantonsspital Aarau AG, Aarau, Aargau, Switzerland
5 Department of Neurological Surgery, Indiana University School of Medicine, Goodman Campbell Brain and Spine, Indianapolis, Indiana, United States

Address for correspondence Alexander Spiessberger, MD, North Shore University Hospital, 300 Community Drive, Manhasset, NY 11030-3876, United States (e-mail: alexander.s.spiessberger@gmail.com).

Keywords ► craniovertebral junction ► far lateral approach ► far medial approach ► anterolateral approach

Abstract

Background Surgical treatment of ventral and ventrolateral lesions of the craniovertebral junction are among the most challenging neurosurgical pathologies to treat. Three surgical techniques, the far lateral approach (and its variations), the anterolateral approach, and the endoscopic far medial approach can be used to approach and resect lesions in this area.

Objective The aim of the study is to examine the surgical anatomy of three skull base approaches to the craniovertebral junction and review surgical cases to better understand the indications and possible complications for each of these approaches.

Methods Cadaveric dissections with standard microsurgical and endoscopic instruments were performed for each of the three surgical approaches, and key steps and surgically relevant anatomy were documented. Six patients with appropriate pre-, post-, and intraoperative imaging and video documentation are presented and discussed accordingly.

Results Based on our institutional experience, all three approaches can be utilized to safely and effectively approach a wide variety of neoplastic and vascular pathology. Unique anatomical characteristics, lesion morphology and size, and tumor biology should all be considered when determining the optimal approach.

Conclusion Preoperative assessment of surgical corridors with 3D illustrations helps to define the best surgical corridor. 360 degree knowledge of the anatomy of craniovertebral junction allows safe surgical approach and treatment of ventral and ventrolateral located lesions using one of the three approaches.
Introduction

The ventral and ventrolateral aspects of the craniocervical junction (CCJ) are anatomically complex and surgically difficult to access. Pathologic lesions found in this area include chordomas, chondrosarcomas, meningiomas, schwannomas, paragangliomas, brainstem cavernomas, and posterior circulation aneurysms, as well as more rare lesions.

In the modern era, three primary surgical approaches are available to access this secluded area: the far lateral approach, the anterolateral approach, and the endoscopic endonasal far medial approach. Fig. 1 gives an overview of these three approaches.

This article aims to review the anatomy of each of these approaches and specific surgical techniques based on cadaveric dissections and patient cases. For each approach exemplary cases are being presented to outline the indications, technical steps, limitations, and possible complications.

Materials

After obtaining Northwell institutional review board approval (IRB 20–0539), anatomical dissections were performed on silicon injected, formalin fixed cadaveric specimens. Standard surgical instruments including monopolar and bipolar cautery, Rhoton microinstruments, endoscope, high speed drill, and operating microscope were used. Each of the approaches under investigation were performed several times on different cadaveric specimens and image documentation performed.

Our departmental procedural database was searched to identify illustrative cases of patients undergoing one of the three procedures under investigation. For each of these cases pre- and postoperative imaging as well as intraoperative video recordings were reviewed.

Results

Far Lateral Approach

The far lateral approach is versatile and includes potential transcondylar, supracondylar, and paracondylar extensions as well as the extreme lateral variant. We utilize one of two variants of soft tissue dissection, as shown in Fig. 2. One can either utilize a midline hockey stick incision and expose the suboccipital bone from the midline elevating a musculocutaneous flap, as seen in Fig. 2A. This variant is similar to a standard suboccipital craniotomy. The vertebral artery should be exposed in the V3 segment prior to its dural entry point. Care must be taken in the rare case of an extradural PICA origin, which can be evaluated on preoperative imaging. Alternatively, a layer wise dissection of the soft tissue layers can be performed. A retroauricular curvilinear incision is extended caudally three finger breadth below the C1 transverse process. Once the subcutaneous tissue has been elevated and reflected anteriorly the posterior border of the sternocleidomastoid muscle (SCM) is identified, the muscle subperiosteally detached from its attachment to the mastoid process (black line in Fig. 2B) and reflected anteriorly.

The attachment site of the splenius capitis muscle lies just posterior and deep to the digastric groove, as seen in Fig. 2C and D. Splenius capitis as well as inferior and superior oblique muscles are then elevated as one layer and reflected. The occipital bone, C1 and C2 transverse process are exposed. At this point the lateral suboccipital craniotomy is performed along with removal of the C1 posterior arch.
with protection of the vertebral artery. In addition, the paracondylar area of the suboccipital bone has to be drilled down to create a surgical corridor along the VA, the V4 segment. Removal of the foramen magnum rim to the occipital condyle is the key step to create a flat corridor to the lower clivus and anterior brainstem. This maneuver shows the creation of a surgical corridor around the VA by drilling of the paracondylar region of the occipital bone. Once sufficient bone removal has been achieved, the dura is opened in a curvilinear fashion, which exposes the neurovascular structures as shown in Fig. 3A and B. Only minor dynamic retraction of the cerebellar hemisphere is necessary to follow the vertebral artery distally toward the PICA origin. As seen in Fig. 3A and B the cranial nerves IX to XII are exposed in their entire subarachnoid course all the way to the jugular foramen and hypoglossal canal. Furthermore, V4 and all PICA segments can be accessed via this approach, as well as the olivary complex. To expose the more ventral aspects of the foramen magnum the atlantooccipital joint can be partially resected following transposition of the V3/V4 segments, which is shown in Fig. 4. This maneuver requires subperiosteal exposure of the V3, followed by transection of the posterior rim of the C1 transverse foramen (Fig. 4A). Preservation of the periosteum, covering the VA and associated venous plexus decreases blood loss by avoiding venous bleeding. After the C1 posterior arch has been resected down to the lateral mass, V3 can be freely mobilized. In the cases outlined in Fig. 4, the dura was opened next, showing a ventral foramen magnum meningioma (Fig. 3E). To maximize exposure of the ventral aspects of the foramen magnum, the dural sleeve of the VA was resected, so that V3 and V4 could be mobilized medially (Fig. 4F), then the posterior-lateral aspect of the atlantooccipital joint has been resected. Following the complete tumor resection an almost straight lateral view lateral to the mobilized VA to the lower clivus can be seen in Fig. 4G.

Fig. 5 outlines three illustrative patient cases. Patient 1 underwent a left far lateral craniotomy for an unruptured left VA-PICA aneurysm. Complete occlusion of the aneurysm was achieved without any intraoperative complications.

Patient 2 underwent a left far lateral craniotomy for resection of a symptomatic foramen magnum meningioma. A complete resection was achieved. The patient required a nasogastric feeding tube postoperatively for a few days, however, she fully recovered without any deficits. Patient 3 underwent a right-sided far lateral craniotomy for the treatment of a ruptured right proximal PICA aneurysm. A successful PICA occlusion and VA-PICA bypass with radial artery graft was performed.

Another example of a patient undergoing a far lateral approach with vertebral artery transposition for resection of a foramen magnum meningioma is shown in Fig. 4. The patient was symptomatic from medullary compression before the surgery. Post-operatively, she suffered from a short period of ipsilateral trapezius muscle weakness, that improved on follow-up.

Anterolateral Approach

This approach exposes the extracranial course of cranial nerves IX-XII as well as the distal V2 segment of the VA as well as V3. It also exposes the C1 and C2 in a direct lateral trajectory allowing for access to the C2 vertebral body, odontoid process, and C1 anterior arch. Fig. 6 outlines the surgical technique in a stepwise fashion. With the patient in a supine position and head laterally rotated, a curvilinear skin incision is performed along the SCM, which is then undermined at the anterior border and reflected posteriorly, which is shown in Fig. 6A. Care is taken to identify and preserve the spinal accessory nerve. After reflection of the SCM the vascular sheath is exposed lying superior to the deep cervical muscle plane, which consists of longus colli and longus capitis muscles. Blunt dissection on the vascular sheath from inferior to superior will allow for identification of CN XII, as it crosses the ICA from lateral to medial. The vascular sheath is then opened to identify CN X which runs between CCA and IJV. Once the cranial nerves have been identified (Fig. 6B), they can be followed proximally toward the hypoglossal canal and jugular foramen (Fig. 6C), even though for a complete exposure all the way to the foramen more bony work is required. Note that complete proximal
exposure often requires a partial mastoidectomy and removal of the styloid process. This proximal exposure is essential for identification and preservation of the cranial nerves and vasculature, and can be used for diverse pathology including nerve sheath tumors and glomus tumors. After reflection of the SCM, the transverse processes of C1, C2, and C3 are easily palpated. Subperiosteal dissection of the muscular attachments at the transverse process (superior and inferior oblique and lateral rectus muscle) can be performed to expose C1, C2, and the sub-axial spine (depending on the incision length), as seen in Fig. 6D. If surgical access to the anterior arch of C1, body or odontoid process of C2 is needed, a vertebral artery transposition might need to be performed. The VA is identified between the C1 and C2 transverse foramen, as it is crossed by the C2 spinal nerve (Fig. 6E). The transverse foramen of C1 and C2 can be opened with Kerrison rongeurs, as shown in Fig. 6F. The corresponding nerve roots are found at each level posterior to the VA, just cranial to the transverse foramen.

An example case is given in Fig. 7, which shows a case of a left-sided hypoglossal schwannoma. The patient has been positioned supine with the head turned to the left. In Fig. 7A the subcutaneous flap has been elevated and reflected anteriorly exposing the SCM. C1 and C2 transverse processes as well as the spinal accessory artery are visible. Once the vascular sheath is dissected, the carotid glomus, the internal and external carotid artery, and the hypoglossal nerve, which crosses the internal carotid artery are visible, as...
seen in -Fig. 7B, C. - Fig. 7D shows the hypoglossal schwannoma, which was resected in total, with no new neurological deficits. - Fig. 8 shows pre- and postoperative images of the patient outlined in - Fig. 7.

**Endoscopic Far Medial Approach**

The first part of the surgery comprises of endonasal stage, where a nasoseptal flap is harvested for later repair of the clival dural defect. In addition, a bi-nostril working space is created by the removal of the middle nasal turbinate and posterior parts of the nasal septum. The working area for the next stage of the surgery, the clival stage, is outlined in - Fig. 8A. Key anatomical landmarks are the sphenoid sinus floor (- Fig. 8B), torus tubarius, and the Eustachian tube (- Fig. 8C). A rubber band is passed from the nose through the choana to the mouth to retract the uvula. The pharyngeal wall muscles as well as the longus colli and rectus capitis anterior muscles are incised vertically in the midline extending from the floor of the sphenoid sinus caudally. As shown in - Fig. 9A the subperiosteal dissection is carried
laterally until the atlantooccipital joint is reached. In the case of Fig. 9A and B a cadaveric specimen was utilized. In Fig. 9A the ICA on the right side has been exposed just caudal to the foramen lacerum. The medial aspect of the atlantooccipital joint in the right side is clearly visualized. Next a high speed burr is used to remove the lower clivus, anterior arch of C1 as well as the medial aspect of the occipital condyle and C1 lateral mass. The dura is then opened in a curvilinear fashion. Fig. 9B and C shows the intradural exposure of the pontomedullary junction and adjacent neurovascular structures. An illustrative patient example is given in Fig. 10. In this case a low clival chordoma has been resected utilizing an endoscopic endonasal far medial approach. A near total resection of the tumor has been achieved without complications. Comparison of pre- and postoperative images are shown in Fig. 10.

Discussion

Pathologic lesions located at the ventral and ventrolateral aspect of the foramen magnum are a surgical challenge. Lesions commonly encountered in this region include low lying clival chordomas, chordomas of the anterior arch of C1, body of C2; foramen magnum meningiomas; VA-PICA aneurysms; CN IX-XII and spinal nerve C1 and C2 schwannomas3–5; This article shows that three surgical approaches, namely the microscopic far lateral approach, the extreme lateral (or anterolateral), and the endoscopic endonasal transclival far medial approach are capable of treating the majority of CCJ lesions (Fig. 11).

What Is the Most Appropriate Surgical Approach?

Selecting the correct approach to the lesions of the CCJ requires thorough preoperative planning and considering...
many factors, including the patient’s individual anatomy, morphometrics and characteristics of the lesion, biological behavior, and the goals of the surgery. For an endoscopic endonasal approach, the availability of a pedicled nasoseptal flap (or alternative reconstruction techniques), the height of the hard palate, tumor size and consistency, and local invasiveness should all be considered. Tumor growth lateral to the clival internal carotid artery is often a limitation in performing gross total resection through an endoscopic endonasal approach. Anatomical considerations of the posterolateral approaches include the dominance and location of the vertebral artery, the sigmoid sinus and jugular bulb patency and location, and the location of the lower cranial nerves. Considering the origin of tumor growth and displacement of the neurovascular structures of the lower CCJ can also be helpful to guide surgical trajectory and safe tumor resection. Pathologies which are optimally approached from far/lateral trajectory are those located at the lateral part of the foramen magnum and uppermost cervical cord (i.e., meningiomas), tumors in the cerebellopontine angle inferior to the internal auditory canal (i.e., schwannoma, meningioma, ependymoma, metastasis), lateral intrinsic lesions of the medulla (i.e., cavernoma), lower cranial nerve schwannomas, and vascular pathologies of the VA, PICA, and vertebrobasilar junction (aneurysm, cavernoma, AVM). With a more lateral orientation even the anterior part of the foramen magnum is reached and thus more ventrally orientated foramen magnum meningiomas and the surgical access can reach as far down as C2.

The anterolateral approach provides an exposure of the extracranial portions of the CN IX-XII schwannomas. This approach can be used as a strictly extrapharyngeal surgical corridor to reach the upper cervical spine (C1/C2 chordomas).

Lastly, the endoscopic far medial approach has its strength in approaching low, paramedian clival lesions, most notably clivus chordomas type III according to Wang’s classification, which often arise slightly off midline and just ventral to the C0/C1 junction. The major limitation of this approach is a significant lateral extension of the tumor.

The surgeons should tailor their approach to optimally visualize the lesion and its surrounding structures to ensure

Fig. 9  Endoscopic far medial approach – cadaveric dissection 2. Panel (A) showing right-sided exposure of the atlantooccipital joint. For demonstration purposes the right ICA has been exposed as well. Panel (B) showing the intradural exposure after drilling of the lower clivus, anterior ring of the atlas as well as the medial aspect of the atlantooccipital joint. (C) Corresponding artistic illustration. C1, atlas; CNIX/X, glossopharyngeal and vagus nerve; CNXII, hypoglossal nerve; ICA, internal carotid artery; M, medulla; O, olives; OC, occipital condyle; P, pons; VA, vertebral artery; white dot, medial aspect of the atlantooccipital joint.

Fig. 10  Endoscopic far medial approach – case example. (A) Preoperative axial MRI showing a low clival chordoma (red dotted area). Panel (B) showing the transection of the posterior pharynx wall in the midline (white vertical line), below the floor of the sphenoid sinus. Panel (C) showing the initial intradural exposure of the lower clivus before drilling of the atlantooccipital joint. Panel (D) showing the final exposure after medial resection of the right atlantooccipital joint. Panel (E) showing the corresponding postoperative MRI after gross total resection. M, medulla; SS, sphenoid sinus floor; VA, vertebral artery. White ellipsoid, resected medial aspect of the atlantooccipital joint.
safe resection and minimize the risk of potential complications. For instance, resection of the occipital condyles can be associated with significant postoperative pain related to violating the innervated joint capsule and potentially mechanical instability. Therefore, resection of only the posteromedial third of the condyles is safe in most cases, whereas removal of more than 50% of the condyles which is rarely indicated generally requires occipitocervical fixation with instrumentation. Applying the concept of strictly limiting the amount of bony removal at the condylar fossa, the occipital condyle, and the jugular tubercle to as little as absolutely necessary to gain access to the lesion has become increasingly popular in recent years. Further critical structures which might be injured when performing a far lateral approach include the hypoglossal nerve (in its canal), CN IX, X, XI in the jugular foramen and the vertebral artery at the CCJ.

The anterolateral approach usually extends just to the medio-anterior border of the condyles and there is no need of condylar resection. Depending on the side dominance of the vertebral artery as well as intracranial vascular variations (e.g., bilateral fetal posterior cerebral arteries), mobilization of the VA to gain exposure to V1 and V2 can carry significant risks.

With ventromedial condyle resection in an endoscopic far medial approach the problem of hypermobility at the atlanto-occipital joint again arises. Further pharyngeal wall transection carries the risk for postoperative infections. In addition, there is a need for an adequate dural reconstruction with a pedicled nasoseptal flap to reduce the risk for CSF fistula. Practically, the hypoglossal canal is a reliable landmark to determine the posterior limit of ventromedial condyle resection. Further structures which account for atlanto-occipital and atlantoaxial stability which may potentially be resected in favor of a more inferior access include the arch of C1, the odontoid process, and the alar ligaments. If those structures are compromised bilaterally, fusion should be considered.

**Conclusion**

Surgical treatment of ventral and ventrolateral-based lesions of the CCJ can be technically challenging and requires a thorough understanding of the complex 360 degree regional anatomy. The choice of approach depends on the exact location of the lesion and consideration of the safest exposure for best results and lowest complication. These cases should be performed by an experienced multidisciplinary team to achieve optimal patient outcomes.

**Conflict of Interest**

None declared.

**References**


