Far Lateral Transcondylar Transtubercular Approach to Lesions of the Ventral Foramen Magnum and Craniovertebral Junction

James K. Liu, MD, Ganesh Rao, MD, Meic H. Schmidt, MD, and William T. Couldwell, MD, PhD

Learning Objectives: *After reading this article, the participant should be able to:*
1. List the indications for performing the far lateral approach and the disease processes that can be accessed using this approach.
2. Describe the techniques for performing the far lateral approach and their nuances.
3. Describe the microsurgical anatomy of the craniovertebral junction that is encountered with the far lateral approach.

The craniovertebral junction, which consists of the lower one third of the clivus, the foramen magnum, and the C1 and C2 vertebrae, is a common site for neoplastic, vascular, congenital, and degenerative lesions of the cranial base. The far lateral transcondylar transtubercular approach (commonly referred to as the "far lateral approach") provides excellent exposure and a lateral viewing trajectory for accessing intradural and extradural lesions located at the ventral foramen magnum and craniovertebral junction, avoiding the need for brain retraction (Figure 1). It usually includes a lateral suboccipital craniectomy, a C1 hemilaminectomy, partial resection of the posteromedial one third of the occipital condyle, and partial resection of the jugular tubercle. The degree of bone removal is tailored for the individual patient, depending on the location and pathology of the lesion. The far lateral approach is useful for several types of tumors in this region, including foramen magnum meningiomas, schwannomas, chordomas, and chondrosarcomas. Vascular lesions, such as vertebral artery–posteroinferior cerebellar artery (PICA) junction aneurysms, vertebrobasilar junction aneurysms, and ventrolaterally located brainstem cavernous malformations, also are readily accessed with this approach. This article discusses the technical details and operative nuances of the far lateral approach with transcondylar and transtubercular extensions.

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Operative Technique

Preoperative Considerations

The far lateral approach is performed on the side of the lateral extension of the lesion. If the lesion is strictly midline, the side is chosen based on the anatomy of the vertebral artery, the sigmoid sinus, and the jugular bulbs. In these cases, the surgeon may consider approaching from the side of the nondominant vertebral artery or nondominant jugular bulb. Preoperative images from MRI, CT, magnetic resonance angiography, magnetic resonance venography, or conventional angiography should be studied carefully to evaluate the features of the lesion; the anatomy of the foramen magnum, occipital condyles, jugular tubercles, and atlantoaxial complex; patency of the vertebral arteries; and dominance of the venous sinuses. If the tumor encases the vertebral artery, a preoperative balloon occlusion test should be performed to determine

Category: Skull base surgery

Key Words: Craniovertebral junction tumors, Far lateral transcondylar approach, Foramen magnum, Cranial base surgery

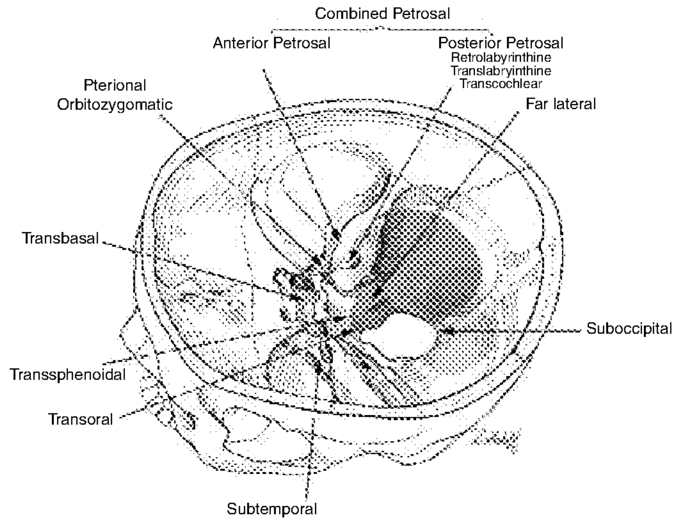

Figure 1. Illustration of various approaches to the cranial base. The far lateral transcondylar transtubercular approach *(dark gray shading)* provides a posterolateral trajectory to the craniovertebral junction to access lesions in the inferior clivus and ventral foramen magnum. The midline suboccipital approach *(light gray shading)*, which provides direct access to the posterior foramen magnum, is limited in accessing ventral or ventrolateral lesions of the foramen magnum. (From Liu and Couldwell, with permission.)

whether it is safe to sacrifice the artery at surgery. Intraoperative monitoring includes somatosensory evoked potentials, motor evoked potentials, brainstem auditory evoked responses, and monitoring of the facial nerve and cranial nerves X, XI, and XII. Cranial nerve X can be monitored with an electromyographic endotracheal tube, and cranial nerves XI and XII are monitored via electrodes placed directly into the sternocleidomastoid muscle and the tongue, respectively.

Positioning and Skin Incision

The patient is placed in the lateral position with the head held in three-point pin fixation with the neck slightly flexed, the vertex angled slightly down, and the face slightly rotated ventrally, so that the ipsilateral external auditory meatus and the mastoid bone are at the highest point (Figure 2). Positioning the head in this manner allows improved exposure of the occipitocervical region and improves the inferior-to-superior viewing angle for the surgeon. An axillary roll is placed, and the contralateral arm rests on a Krauss armrest. The elevated arm is distracted inferiorly toward the foot of the table to provide more room for the surgeon above the shoulder. All pressure points are carefully padded with foam or gel pads, and the patient is secured to the operating table with adhesive tape to allow safe rotation of the table during the operation to improve the surgeon's line

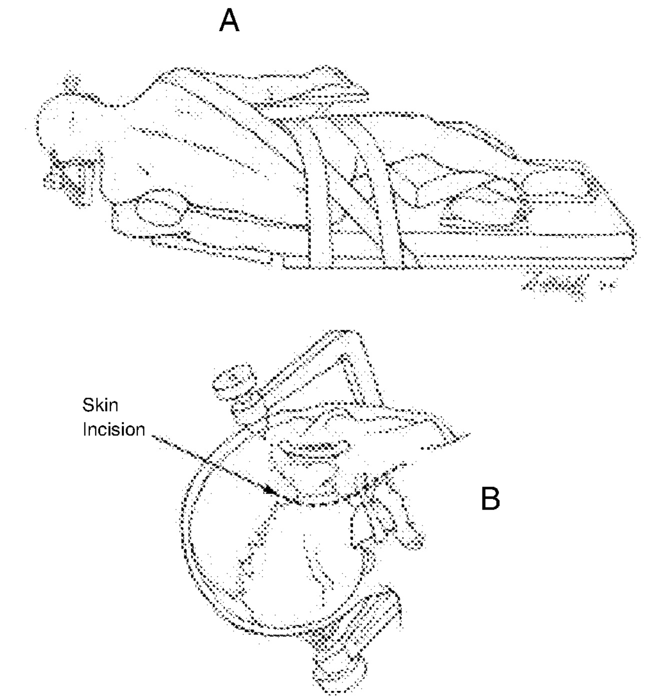

Figure 2. *A*, Diagram showing the patient placed in the lateral position. The head is held in three-point pin fixation with the neck slightly flexed, the vertex angled slightly down, and the face slightly rotated ventrally, so that the ipsilateral external auditory meatus and the mastoid bone are at the highest point. *B*, Retroauricular curvilinear skin incision *(dotted line)*. (From Liu and Couldwell, with permission.)

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of sight. Intravenous glucocorticoids, antibiotics, and mannitol are administered at the time of the skin incision.

A retroauricular curvilinear skin incision starts approximately 2 to 3 cm behind the ear and continues inferiorly into the neck over the posterior border of the sternocleidomastoid muscle to approximately C3 or C4 (Figure 2). The skin flap is elevated in two layers. The incised skin and galea are elevated first to expose the underlying pericranium above the superficial neck fascia, which may be harvested as a fascial graft for later watertight dural closure. The pericranium and the superficial fascia are then elevated to expose the underlying musculature.

Muscle Dissection and the Suboccipital Triangle

Anatomically, three layers of muscle are identified during the dissection. The superficial layer, which includes the trapezius and sternocleidomastoid muscles; and the middle layer, which consists of the splenius capitis, longissimus capitis, and semispinalis capitis muscles, are incised and reflected as a single layer to expose the suboccipital triangle (Figure 3), which is bound by the deep layer of muscles—medially by the rectus capitis posterior major, inferiorly by the inferior oblique, and superolaterally by the superior oblique muscle. The rectus capitis major muscle inserts superiorly on the inferior nuchal line and inferiorly on the spinous process of C2; the inferior oblique muscle inserts superiorly on the transverse process of C1 and inferiorly on the spinous process of C2; and the superior oblique muscle inserts superiorly at the temporo-occipital suture and inferiorly on the transverse process of C1. The suboccipital triangle, which involves the dorsal ramus of the C1 nerve root and the V3 horizontal segment of the vertebral artery, can be opened by detaching the insertions of the superior and inferior oblique muscles from the transverse process of C1 and reflecting them posteriorly. The rectus capitis major is detached from the inferior nuchal line and reflected posteriorly, after which the C1 lamina and vertebral artery will become more apparent. The vertebral artery is covered by a venous plexus, sometimes referred as the suboccipital cavernous sinus. Further exposure of the laminae of C2 or C3 may be performed if more inferior exposure is needed.

Exposure of the Extradural Vertebral Artery

Exposure and control of the extradural vertebral artery can be achieved by identifying its extradural course from the foramen transversarium of C2 to the occiput. The ventral ramus of the C2 nerve root, found between the laminae of C1 and C2, can be traced laterally until it crosses dorsally to the vertical segment of the vertebral artery, coursing between the foramen transversarium of C2 and C1 (Figure 4). As the vertebral artery exits the foramen transversarium of C1, it is encased in a venous plexus and courses posteriorly behind the lateral mass of C1 in the J-shaped vertebral groove and turns medially to pierce the atlanto-occipital membrane and dura mater. Several small muscular branches and the posterior meningeal artery arise from the horizontal segment of the vertebral artery, which can be safely coagulated. In some cases, the posterior spinal artery and the PICA arise extradurally and can be injured. Subperiosteal dissection of the vertebral artery from the vertebral groove reduces bleeding from the venous plexus by leaving the periosteal sheath around the artery intact. The atlanto-occipital membrane is sharply divided to expose the underlying dura.

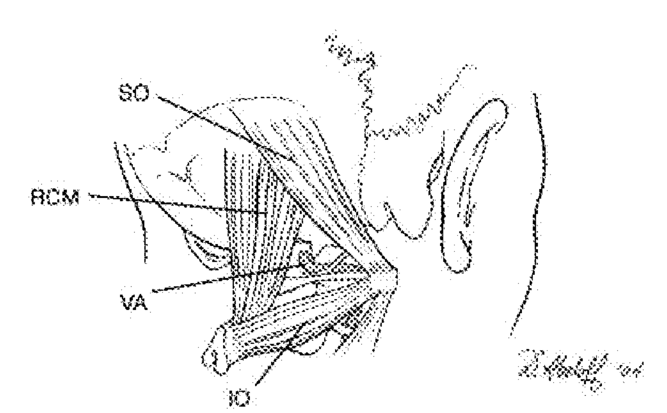


Figure 3. Illustration showing the suboccipital triangle, which is bound medially by the rectus capitis posterior major *(RCM)* muscle, inferiorly by the inferior oblique *(IO)* muscle, and superolaterally by the superior oblique *(SO)* muscle, serves as an anatomic landmark for identifying the dorsal ramus of the C1 nerve root and the V3 horizontal segment of the vertebral artery *(VA)*. (From Liu and Couldwell, with permission.)

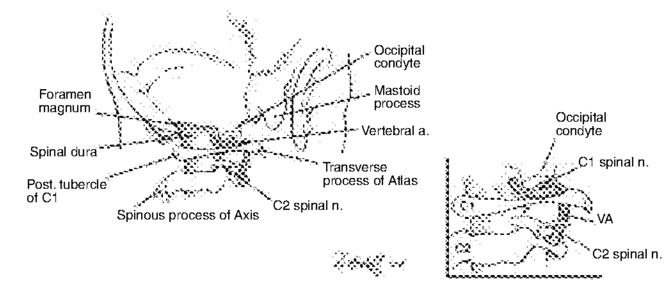


Figure 4. Diagram of the course of the vertebral artery. The ventral ramus of the C2 nerve root, found between the laminae of C1 and C2, can be traced laterally until it crosses dorsally to the vertical segment of the vertebral artery, coursing between the foramen transversarium of C2 and C1. As the vertebral artery exits the foramen transversarium of C1, it is encased in a venous plexus and courses posteriorly behind the lateral mass of C1 in the vertebral groove and turns medially to pierce the atlanto-occipital membrane and dura. (From Liu and Couldwell, with permission.)

Vertebral artery transposition can be performed by opening the foramen transversarium of C1 with a high-speed diamond drill and mobilizing the artery inferomedially away from the atlanto-occipital joint. Vertebral artery transposition is not necessary in most cases for the standard far lateral transcondylar approach. However, this maneuver is important for gaining a direct lateral (extreme lateral) trajectory to resect the lateral mass of C1, the lateral aspect of the occipital condyle, the odontoid process, and the inferior clivus, as described in the extreme lateral approaches for resection of extradural lesions of the craniovertebral junction. Subsequent occipitocervical stabilization, which is necessary if the atlanto-occipital joint is resected, can be performed unilaterally with the same surgical exposure immediately after resection.

Suboccipital Craniectomy and C1 Hemilaminectomy

A lateral suboccipital craniectomy or craniotomy is performed initially with a craniotome and rongeurs. The craniectomy usually extends toward the midline medially, to the inferior nuchal line superiorly, to the posterior rim of the foramen magnum inferiorly, and up to the occipital condyle laterally (Figure 5). To provide more superior access to the cerebellopontine angle, the craniectomy can be extended up to the transverse sigmoid junction. The sigmoid sinus and jugular bulb are exposed with rongeurs and a high-speed drill. The posterior condylar emissary vein will be encountered as it travels from the jugular bulb and exits the condylar fossa via the condylar canal to join the extradural venous plexus. Hemostasis can be achieved by packing the vessel with Surgicel (Johnson & Johnson). An ipsilateral hemilaminectomy of C1 improves the dural exposure inferiorly. More inferior exposure for lower-lying lesions can be created by removing the hemilamina of C2 and C3.

Transcondylar Resection

Extradural reduction of the occipital condyle is one of the key maneuvers in maximizing exposure to the ventral aspect of the craniovertebral junction while avoiding brainstem retraction (Figure 6). Anatomic morphometric studies have demonstrated that partial condylar resection increases the angle of exposure, the working space at the level of the foramen magnum, and visualization of the ventral and ventrolateral aspect of the craniovertebral junction and the contralateral aspect of the inferior clivus. Recommendations in the literature for the degree of occipital condyle removal vary widely, ranging from no resection to complete condyle resection. Our experience indicates that removal of the posterior and medial one third of the condyle usually is adequate if more ventral exposure is needed. It is important to study preoperative CT images of the cranial base, because not all patients require condylar resection. Condylar resection may not be necessary to increase the surgical corridor (Figure 7) if the patient has small occipital condyles and a large foramen magnum, or if the tumor has eroded the condyle and displaced the brainstem medially. If 50% or more of the condyle has been resected or

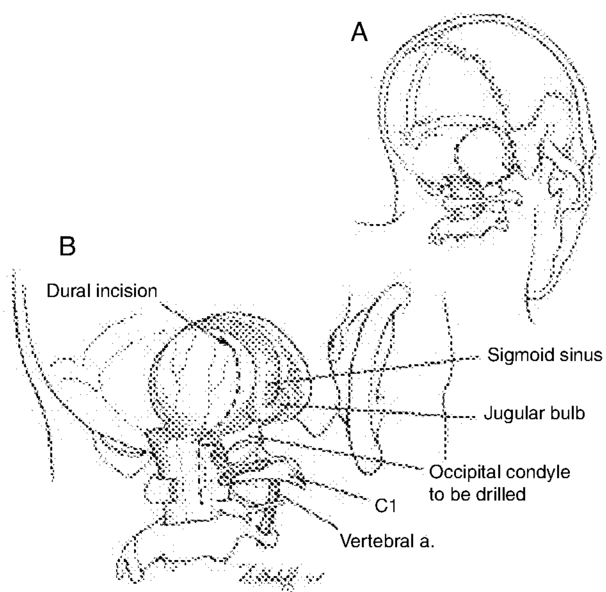


Figure 5. *A,* Illustration of retrosigmoid lateral suboccipital craniectomy *(dotted line),* extending toward the midline medially, to the inferior nuchal line superiorly, to the posterior rim of the foramen magnum inferiorly, and up to the occipital condyle laterally. *B,* The craniectomy can be extended up to the transverse sigmoid junction to provide more superior access to the cerebellopontine angle, as shown. The dural incision *(dotted line)* is made in a curvilinear fashion several millimeters posterior to the sigmoid sinus and extends inferiorly toward the C2 lamina, staying posterior to the vertebral artery where it pierces the dura. A relaxing "T" incision is made just superior to the entry of the vertebral artery, leaving a cuff of dura around the vertebral artery for later watertight closure. (From Liu and Couldwell, with permission.)

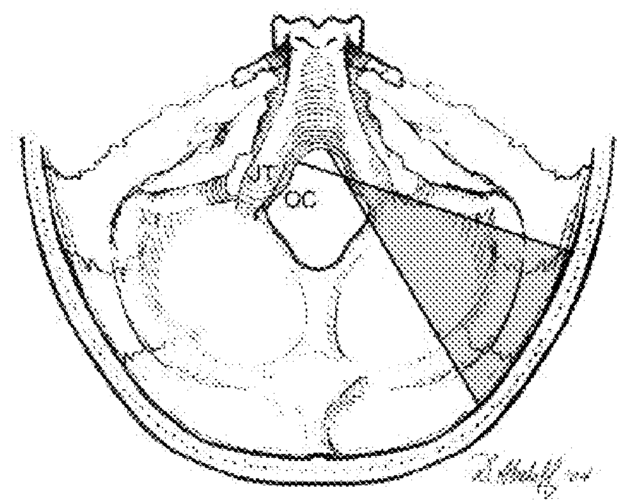


Figure 6. Illustration showing reduction of the occipital condyle *(OC)* and jugular tubercle *(JT),* which increases the angle of exposure and visualization of the ventral foramen magnum past the midline of the clivus.

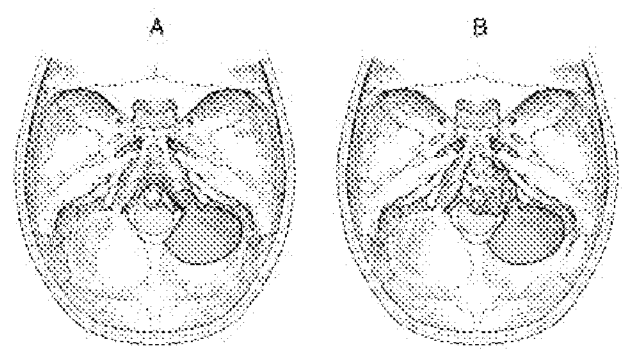


Figure 7. *A,* Diagram demonstrating a ventral foramen magnum tumor compressing the brainstem. A far lateral transcondylar transtubercular approach *(shaded in gray)* provides excellent exposure for a lesion in this region. *B,* A very large tumor of the clivus compressing the ventral and lateral aspects of the brainstem that has eroded the occipital condyle. A far lateral approach without transcondylar or transtubercular resection would be sufficient in removing this tumor because the tumor has created a large surgical window by displacing the brainstem medially. Postoperative occipitocervical stabilization should be strongly considered because the tumor has eroded a significant portion of the occipital condyle.

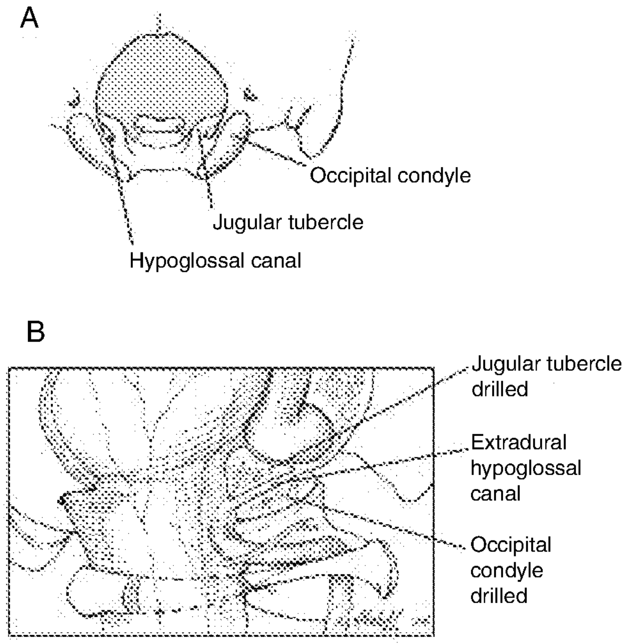


Figure 8. *A*, Illustration showing inferior view of the base of the cranium and the anatomic relationship of the jugular tubercle, hypoglossal canal, and occipital condyle. The jugular tubercle is situated superior to the hypoglossal canal. The occipital condyle is inferior to the hypoglossal canal. *B*, Extradural reduction of the posterior third of the occipital condyle and the superomedial aspect of the jugular tubercle are the key maneuvers for gaining access to the ventral foramen magnum. (From Liu and Couldwell, with permission.)

destroyed by the lesion, the craniovertebral junction becomes more unstable, and occipitocervical stabilization should be strongly considered.

The posteromedial aspect of the occipital condyle is removed with a high-speed diamond drill, taking care to protect the vertebral artery (Figure 8). Once the cortical layer of bone is removed, the soft cancellous bone is encountered. Venous bleeding from the condylar emissary vein within the condylar canal is controlled with bone wax and Surgicel. Further drilling will expose another cortical layer of bone that covers the hypoglossal canal, which is situated superior to the occipital condyle and inferior to the jugular tubercle. The hypoglossal canal contains the hypoglossal nerve, a meningeal branch of the ascending pharyngeal artery, and the venous plexus of the hypoglossal canal, which allows the basilar venous plexus to communicate with the marginal sinus that encircles the foramen magnum. Identification of the medial aspect of the hypoglossal canal usually indicates that approximately one third of the posterior condyle has been removed. Because the hypoglossal canal is directed anteriorly and laterally at a 45-degree angle with the sagittal plane, further skeletonization of the canal to its lateral extent usually results in removal of the lateral aspect of approximately the posterior two thirds of the condyle. Bone removal is next directed superiorly toward the inferior margin of the jugular bulb.

Transtubercular Resection

Extradural reduction of the jugular tubercle is the key step in maximizing intradural exposure across the anterior surface of the brainstem and midclivus. This maneuver also may make it easier to visualize some vertebrobasilar junction aneurysms and vertebral artery–PICA aneurysms. The jugular tubercle is a rounded prominence found at the junction of the basilar and condylar parts of the occipital bone. It is situated slightly medial and inferior to the jugular bulb, superior to the hypoglossal canal (tubercular triangle), and medial to the jugular foramen (Figure 8). Failure to reduce a prominent jugular tubercle adequately may result in an obstructed view of the basal cisterns and clivus anterior to the lower cranial nerves.

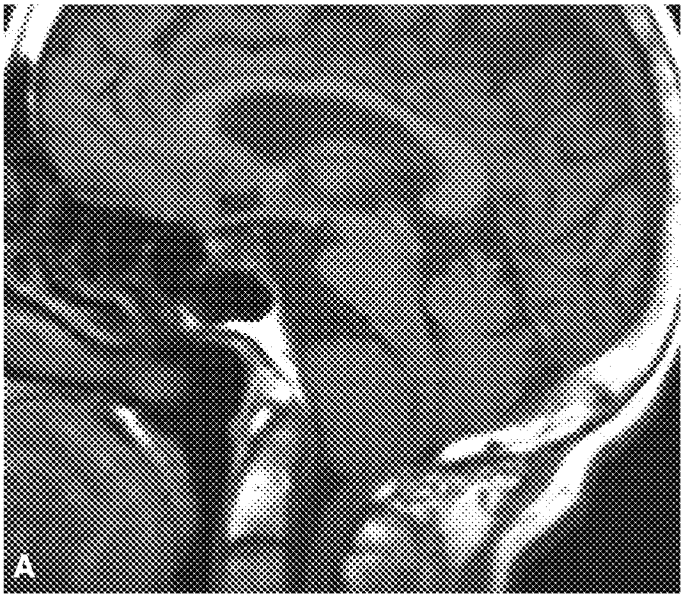
Reduction of the jugular tubercle should focus on the superomedial aspect portion, which is the major area of obstruction. Cranial nerves IX, X, and XI , which cross over the posterior aspect of the jugular tubercle into the jugular foramen, are in very close proximity and may be at risk of damage by direct trauma, stretching of the dura mater, and heat generated by the drill. To minimize these risks, the center of the tubercle is cored out with a high-speed diamond drill and copious irrigation, leaving an eggshell-thin layer of bone covering the dura mater that can be elevated with a microdissector.

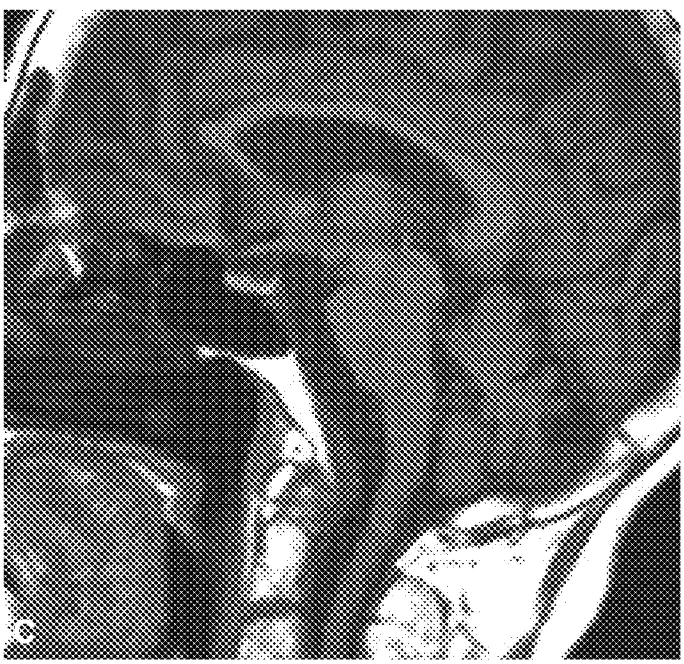
Intradural Exposure

Intradural exposure is necessary for accessing intradural lesions, such as meningiomas, schwannomas, aneurysms, and vascular malformations (Figures 9 and 10). A curvilinear incision of the dura is made several millimeters posterior to the sigmoid sinus, extending inferiorly toward the C2 lamina and staying posterior to the vertebral artery where it pierces the dura mater (Figure 5). We prefer to extend the dural opening anteriorly in a "T" fashion, just superior to the vertebral artery, to enable increased exposure. A dural cuff is preserved around the vertebral artery for later watertight closure. The incision can be extended up to the junction of the transverse-sigmoid sinus if more exposure of the cerebellopontine angle is needed. The anterior leaflet of the dura mater is reflected laterally and is held with tacking sutures for maximal exposure. Adequate reduction of the occipital condyle and jugular tubercle should provide a straight surgical trajectory to the craniovertebral junction parallel to the intracranial course of the vertebral artery. Structures of the inferior aspect of the cerebellopontine angle and the cerebellomedullary angle are visualized. Sharp arachnoid dissection is performed, and cranial nerves V through XII, the basilar artery, the vertebral artery, the vertebrobasilar junction, the PICA, and the anteroinferior cerebellar artery can be visualized (Figure 10).

Closure

A primary watertight closure of the dura should be performed. If necessary, an autologous pericranium or fascial graft can be harvested from the neck wound and supplemented with autologous fat and fibrin glue. The exposed mastoid air cells are closed with bone wax. The muscle layers are reapproximated carefully to avoid postoperative leakage of cerebrospinal fluid (CSF). Temporary CSF diversion with a lumbar drain can be used to promote sealing of the wound and reduce the risk of a pseudomeningocele developing.





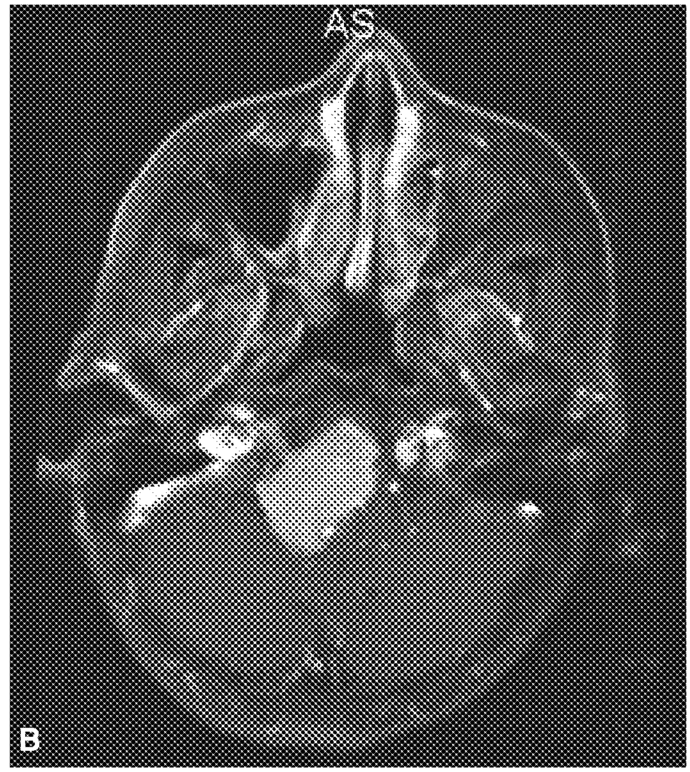


Figure 9. *A* and *B*, Preoperative MRI scans. Sagittal (*A*) and axial (*B*) views demonstrate a large, ventrally based foramen magnum meningioma compressing the cervicomedullary junction in an 82-year-old woman who presented with progressive myelopathy. Gross total resection was achieved by use of a far lateral approach. *C*, Postoperative sagittal MRI scan.

Occipitocervical Stabilization

Transcondylar resection has the potential to destabilize the craniovertebral junction. Integrity of the occipital condyle, C1 lateral mass, and all the ligamentous attachments at the craniovertebral junction contribute most to the stability of the craniovertebral junction. If the integrity of these structures is compromised, either by resection or by the tumor itself and instability results, an occipitocervical fusion procedure becomes necessary. Vishteh et al. performed a biomechanical study demonstrating statistically significant hypermobility at the atlanto-occipital joint when 50% or more of the occipital condyle was resected. Progressive resection of the condyle also produced increased hypermobility at C1–C2, especially after 75% resection. We recommend occipitocervical fusion when 50% or more of the occipital condyle is resected.

Conclusion

The far lateral approach provides excellent exposure for treating intradural and extradural lesions located in the inferior clivus, ventral foramen magnum, ventral and ventrolateral brainstem, and craniovertebral junction without brain retraction. Reduction of the occipital condyle and jugular tubercle is the key maneuver in improving the lateral viewing trajectory past the midclivus; however, these maneuvers should be tailored to the individual, depending on the pathological condition. Instability may result if

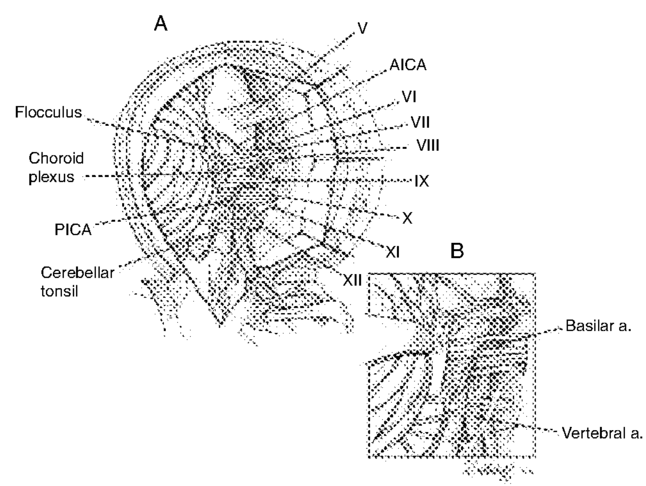


Figure 10. Diagram illustrating intradural exposure of the far lateral approach. AICA, anteroinferior cerebellar artery; PICA, posteroinferior cerebellar artery. (From Liu and Couldwell, with permission.)

50% or more of the occipital condyle is resected or destroyed by the lesion; in such a case, occipitocervical stabilization should be considered.

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