CERVICAL SPINE TUMORS SURGERY: SURGICAL EXPOSURE, CONTROL, AND MOBILIZATION OF THE VERTEBRAL ARTERY

CIRURGIA DE TUMORES DA COLUNA CERVICAL: EXPOSIÇÃO CIRÚRGICA, CONTROLE E MOBILIZAÇÃO DA ARTÉRIA VERTEBRAL

CIRUGÍA DE TUMORES DE LA COLUMNA CERVICAL: EXPOSICIÓN QUIRÚRGICA, CONTROL Y MOVILIZACIÓN DE LA ARTERIA VERTEBRAL

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ABSTRACT

The overall morbidity associated with cervical spine tumor surgery is approximately 20%, necessitating the development of mitigation strategies. Several critical anatomical structures inside the cervical spine are vulnerable to iatrogenic injury, adding significantly to morbidity. These include the spinal cord, nerve roots, and vertebral artery (VA). Despite the emphasis on meticulous neuro-dissection from the tumor mass in training programs, a majority of surgeons still refrain from working around the VA. This creates a persistent fear of harming the VA, resulting in partial tumor removal or more difficult angles of attack on the tumor, requiring greater retraction of the neural tissue and contributing to morbidity. The VA can be exposed with a precise surgical technique that minimizes the iatrogenic lesion and the potential morbidity. In this paper, the authors review the surgical anatomy of the vertebral artery, including its variants, and analyze the rationale and feasibility of exposing, skeletonizing, controlling, and mobilizing the VA using the lateral approaches to cervical spine and craniovertebral junction (CVJ). ***Level of Evidence V; Expert Opinion.***

Keywords: Cervical Vertebrae; Vertebral Artery; Cervical Spine; Neoplasms.

RESUMO

A taxa de morbilidade global relacionada à cirurgia de tumores da coluna cervical é de aproximadamente 20%, o que torna necessário o desenvolvimento de estratégias de mitigação. Diversas estruturas anatômicas presentes na coluna cervical, como a medula espinhal, raízes nervosas e artéria vertebral, podem sofrer danos cirúrgicos iatrogênicos, o que pode aumentar a morbilidade. Os programas de treinamento cirúrgico priorizam o aprendizado da dissecção tumoral em relação às estruturas nervosas, porém costumam apresentar lacunas quanto à exposição e ao manejo da artéria vertebral quando esta está envolvida pelo tumor. O temor de danificar a artéria vertebral frequentemente limita a remoção total do tumor ou exige o uso de ângulos de abordagem menos favoráveis, resultando em uma retração excessiva do neuro-eixo, o que aumenta a morbilidade. A artéria vertebral pode ser exposta segundo uma técnica cirúrgica precisa que reduz ao mínimo a sua lesão iatrogénica. Neste artigo de revisão, os autores analisam a anatomia cirúrgica da artéria vertebral, abrangendo suas variantes e anomalias. Além disso, discutem a argumentação e a viabilidade da exposição, esqueletonização, controle e mobilização da artéria vertebral por meio das abordagens laterais à coluna cervical e à charneira crânio-vertebral. ***Nível de Evidência V; Opinião do Especialista***.

Descritores: *Vértebras Cervicais; Artéria Vertebral; Coluna Cervical; Neoplasias.*

RESUMEN

La tasa de morbilidad general relacionada con la cirugía de tumores de la columna cervical es de aproximadamente el 20%, lo que requiere el desarrollo de estrategias de mitigación. Varias estructuras anatómicas en la columna cervical, como la médula espinal, las raíces nerviosas y la arteria vertebral, pueden sufrir daño quirúrgico iatrogénico, lo que puede aumentar la morbilidad. Los programas de capacitación quirúrgica priorizan la disección del tumor sobre las estructuras nerviosas, pero a menudo carecen de conocimiento sobre la exposición y el manejo de la arteria vertebral cuando está afectada por el tumor. El temor a dañar la arteria vertebral a menudo limita la extirpación total del tumor o requiere el uso de ángulos de abordaje menos favorables, lo que resulta en una retracción excesiva del neuroeje, lo que aumenta la morbilidad. La arteria vertebral puede exponerse utilizando una técnica quirúrgica precisa que minimiza la lesión iatrogénica. En este artículo de revisión, los autores analizan la anatomía quirúrgica de la arteria vertebral, abarcando sus variantes y anomalías. Además, se analiza la justificación y la viabilidad de exponer, esqueletizar, controlar y movilizar la arteria vertebral mediante abordajes laterales a la columna cervical y la charnella craneovertebral. ***Nivel de Evidencia V; Opinión de Expertos.***

Descriptores: *Vértebras Cervicales; Arteria Vertebral; Columna Cervical; Neoplasias.*

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INTRODUCTION

Cervical spine and cranio-vertebral junction (CVJ) tumors may displace, enclose, and infiltrate the vertebral artery (VA). Whenever VA is involved, surgery becomes more technically demanding and prone to complications, such as hemorrhage and stroke, or tumor partial resection, which compromise disease-free survival.

Understanding the surgical anatomy of the VA and its branches is critical for diagnosing VA anomalies and determining tumor resectability concerning neuroaxis components such as nerves, medulla, and spinal cord. When bone anomalies exist, the likelihood of VA anomalies rises. To obtain an optimal oncological treatment, a comprehensive understanding of tumor biology and recurrence patterns is also essential. These characteristics, along with the tumor's location, will dictate the surgical approach and the intrinsic goals.

This narrative overview addresses pre-operative and intra-operative strategies to mitigate the risk of vertebral artery injury during cervical spine tumor surgery.

Surgical anatomy of the vertebral artery and surgical implications

The vertebral arteries, one on each side, usually emerge from the subclavian arteries and converge to form the basilar artery. VA is separated into four segments based on its anatomical relationship to the cervical vertebrae: V1, V2, V3, and V4. (Table 1)

Table 1. The four segments of the vertebral artery about its position in the cervical spine.

V1 – Pre-foraminal	from its origin on the SCA to its entry into the C6 TF
V2 - foraminal	from its entry into the C6 TF to the C2 TF
V3 - suboccipital	from the C2 TF to its dural penetration at the level of the FM
V4 - intracranial	from its dural penetration to the vertebrobasilar junction

SCA: Subclavian artery; TF: transverse foramen; FM: foramen magnum.

Subaxial cervical spine

The V1 segment is the most vulnerable portion of the VA because its path is entirely extraosseous, anterior to the longus colli and longus capitis muscles. It travels between the prevertebral muscle and the bone of the transverse process, forming a bayonet shape before entering the transverse foramen (TF). As a result, VA is more exposed in its intertransverse segments, where it is protected only by the intertransversary muscles. When the VA enters the TF, the transition between V1 and V2 is normally at C6, but this is not always true. Instead of entering the TF of V6, the VA can enter at C5 (5.9%), C7 (1.3%), C4 (1.3%9, or even C3 (0.3%).[1] Therefore, it is critical to determine in the preoperative MRI in which foramen V1 becomes V2.

As it ascends in the subaxial cervical spine, the VA becomes more posterior and medial in location. The distance between the two vertebral arteries is shorter at the level of the C3 vertebra, making corpectomies at that level more dangerous, especially when the tumor softens the vertebral body wall. Concerning the lateral margin of the uncovertebral joint, the medial margin of the VA is closer at C5-6. Working on the disc at this level requires extra caution. The presence of VA loops that intrude inside the disc or erode the lateral wall of the vertebral body may also result in additional constraints.

Cranio-Vertebral Junction

V2 becomes V3 at the TF of C2. When V3 pierces the dura at the CVJ, it becomes V4.

At the CVJ, the VA forms loops that enable adjustment to rotational and flexion-extension movements of the head. The surgeon can take advantage of these loops to mobilize the VA away from the lateral wall of the CVJ and gain direct access to the tumor epicenter. While aging, vascular loops may expand and protrude between muscle groups, rendering them more vulnerable to surgery.

In this region, an important variation is the intradural course of the VA from C2 rostrally, which generally pierces the dura between C1 and C2, and must be identified pre-operatively. Another common variation is an extracranial origin of PICA, which may be present in 5-20% of the population.[1-2] The VA is covered by the occipitoatlantal membrane, which can be calcified or ossified. In this scenario, the VA portion in the posterior groove of C1 becomes partially or totally encased in a bony channel also referred to as arcuate foramen (15–28%),[1] making it harder to expose the VA. The periosteal sheath continues latero-medially along the V3 segment to the medial dural ring, which is the intradural entry point of the VA, located on average 12 mm from the midline.[3]

The V4 segment begins at the dural ring, initially located above the C1nerve rootlets, in front of the dentate ligament and spinal roots of the accessory nerve. This segment runs anteriorly and cranially, passing beneath and occasionally between the rootlets of the hypoglossal nerve,

to merge with the contralateral vessel into the basilar trunk at the pontomedullary junction. When treating CVJ lesions, the following V4 branches should be identified: PICA, ASA, PSA, and perforators. PICA is usually displaced posteriorly by intradural tumors and, hence, is the first to be seen in the posterior approach. Perforating arteries arise from the PICA, the distal VA, the ASA and its branches, and from the anteromedial and anterolateral medullary arteries. The perforators prevent the mobilization of these arteries during tumor dissection.

The topographical relationship of the intradural tumors with the VA can predict the displacement of cranial nerves by the tumor. If the tumor is positioned below the VA entry, the cranial nerves are pushed upwards, making dissection easier around the tumor. In all other situations, cranial nerve displacement is unpredictable.[4]

Vertebral artery hemodynamics

In terms of caliber, absolute symmetry is rare, as is atresia of one of the arteries. For this reason, when there is no flow-void seen on MRI or VA contrast enhancement on angio-CT, a tumor-caused arterial compression or occlusion should be suspected.

In general, one artery, usually the left one, is dominant. As a result, wherever possible, it is best to operate on the tumor on the side of the non-dominant artery. In this situation, if an iatrogenic injury occurs, the consequences may be typically modest. However, the outcomes of VA surgical injury are relatively unexpected due to the lack of compensatory hemodynamics observed at the Willis polygon. Patency of the dominant VA may not be sufficient to compensate for the loss of a non-dominant VA. A pre-operative balloon test occlusion is recommended at the start of the surgeon's learning to skeletonize the VA curve, or when the dominant VA cannot be preserved while resecting a tumor or when VA are encased bilaterally.

Congenital anastomosis between the carotid artery and the vertebrobasilar system can be formed by intradurally situated trigeminal, otic, and hypoglossal arteries, whereas the proatlanto artery is extracranially located. The VA gives rise to radiculomeningeal and muscular branches, the latter of which join with the muscular branches of the ascending cervical artery, the deep cervical artery, and the external carotid artery to form a vascular network. When the VA is blocked proximally, this network allows the VA to be refilled distally; surprisingly, this vascular network is not evident on angiography.

Risk factor for intraoperative VA injury

Any form of VA abnormal caliber can be easily observed on axial MRI or CT-scan sections, or angiography, if necessary.

Extrinsic tumor compression is denoted by a localized reduction in VA caliber or, even, occlusion. In this case, extra care should be taken to dissect the VA away from the tumor. Fortunately, most tumors respect the periosteal sheath and the adventitia of the VA, except histiocytosis, sarcomas, and aneurysmal bone cysts, which infiltrate the arterial wall and suppress the cleavage plane. When a tumor completely envelops VA, no face of the vessels can be identified before dissection. In this scenario, it is advisable to identify the VA proximal and distal to the tumor to grant full VA control.[3] Identification of VA becomes difficult when bone abnormalities obliterate surgical anatomical landmarks.

In the case of radiation therapy, fibrosis, or VA injury from previous surgery, no dissection plane exits or VA wall may even be weakened, making tumor separation from VA extremely difficult and prone to iatrogenic injury.[5] In this case, it is advisable to prepare to sacrifice the VA.

Surgical exposure of the Vertebral Artery

The pre-operative work-up

The pre-operative imaging should predict the location of the VA and its intimate relationship with the tumor. MRI and CT should be used to carefully evaluate the following features: VA dominance and variation evaluation, bone anomalies obliterating surgical landmarks, VA encasement and stenosis, tumor configuration and nature, and the putative necessity to sacrifice the VA (Figure 1). Except for balloon test occlusion or pre-operative embolization of specific malignancies, angio-CT or angio-MRI can accurately determine VA encasement and stenosis, rendering classical angiography unnecessary.[6,7] A meticulous pre-operative analysis improves the surgical strategy, increases tumor removal, and reduces surgical morbidity. (Table 2)

Surgical approaches

Precise surgical technique should permit the exposure of any of the VA segments without major problems. The VA is the center of the surgical exposure offered by the lateral approaches.

The anterolateral approach (ALA) is the most reliable technique and can be applied at any level of the cervical spine. It grants a unique surgical trajectory to the prevertebral space of C1–C2 laterally, to the cranio-vertebral junction in an anterosuperior direction, and lesions extending down the cervical column. At the V2 and V3 segments, it is important to work outside the periosteal sheath surrounding the VA and its venous plexus.

For CVJ intradural lesion around the V3 and V4 segment of the VA, another valuable option is the posterolateral approach (PLA) based on mobilization and transposition of VA from the posterior arch of C1.

This article describes the particular technical tips for each VA segment and potential complications. Also discussed are various extensions of the lateral approach from the VA exposure at each level.

Anterolateral approach

To expose anterolateral bony structures and the underlying tumor in the cervical spine, the VA must often be mobilized or transposed from the transverse foramina during surgery. The anterolateral approach (ALA) is a versatile approach that allows for an excellent exposure and control of the VA in the V1, V2, and V3 segments, depending on the extension of skin incision and cervical dissection with a single positioning of the patient.[8,9]

The patient is positioned in the supine position with a cushion under the shoulder and the head slightly extended and rotated to the contralateral side, 10º for tackling V1 and V2 segments, or an anterior lesion at the V3 segment. For V3 segment posterior lesions, the head is rotated 40º to project the posterior arch of the atlas into the field.

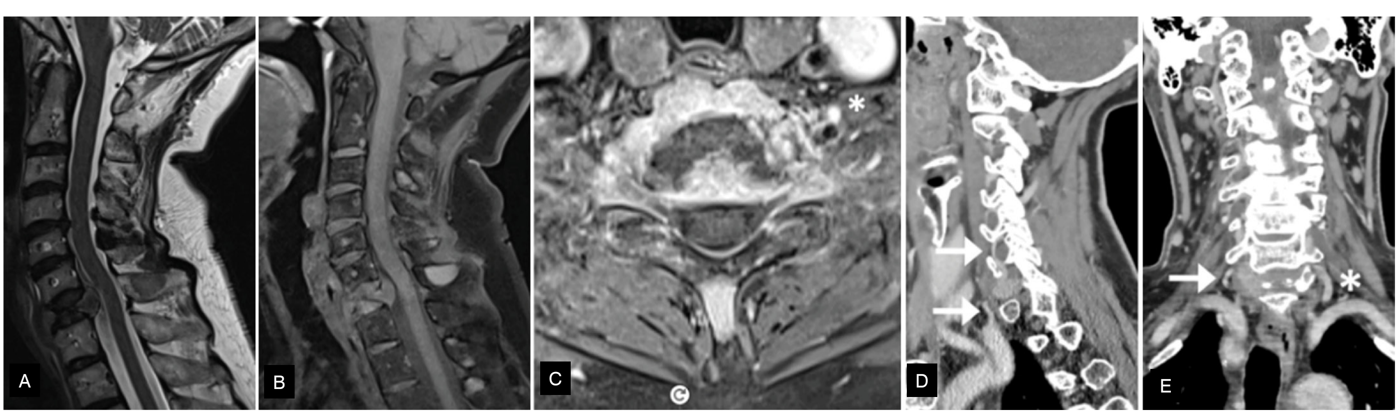
Table 2. Tips for a successful exposure of the vertebral artery.

Pre-operative Imaging Assessment
VA surgical anatomy and presence of variants
bone anomalies that efface surgical landmarks
if possible, plan approach on non-dominant VA side
topographical relationship of the VA with the tumor
VA caliber or occlusion on both sides
TF in which V1 becomes V2
Intra-operative technique
VA and venous plexus subperiosteal dissection from bone
VA skeletonization from TF above and below the tumor
CVJ VA loops transposition and mobilization away from the lateral wall
minimal drilling of the occipital condyle to avoid instability

VA: Vertebral artery; TF: transverse foramen.

The skin incision follows the medial edge of the SM. The anterolateral route explores a natural corridor, free of vessels and nerves between the sternocleidomastoid muscle (SM), laterally, and the internal jugular vein (IJV), carotid artery (CA), trachea, and esophagus medially. Except for above C3, where the accessory nerve must be managed, no important neurovascular structure crosses the surgical region while exposing the transverse process.

When approaching longus colli and longus capitis, the prevertebral fascia is exposed and incised medially or laterally along the sympathetic chain to retract it and thus avoid Horner's syndrome. After palpating the transverse process, the longus colli muscle is cut over it. First, it is mandatory to check that VA is running in the transverse foramen and not in front of it. A smooth spatula is then used to elevate the periosteum of the transverse process. At each TF, the venous plexus is surrounded by the periosteal sheath that encircles the VA. VA is a free mobile within the subperiosteal sheath to account for the neck movements. The periosteum inside the transverse foramen is then separated from the bone. In the space between bone and periosteum, a 2mm Kerrison is pushed and the anterior wall of the foramen is opened, thus, unroofing the TF. A subperiosteal dissection is the key technical bloodless maneuver for releasing the VA from the TF, for easier mobilization and control of the vessel. If venous bleeding develops, it is easily treated with tamponade or hemostatic medications. By working extraperiosteally, the venous plexus is kept inside the periosteal sheath. The VA is then entirely exposed between the two transverse foramina with resection of the small intertransverse muscles. The anterior aspect of



62-year-old female, without previous history of tumor, presenting with neck pain VAS 10 and mild myelopathy MJoA 15. A and B: T2-weighted and T1-TSE-Dixon sagittal MRI showing C7 vertebral body collapse, posterior involvement, and spinal cord compression denoting a SINS of 13; C: T1-TSE-Dixon axial MRI demonstrating "collapse" of right VA (arrows) and normal caliber left VA (asterixis) and C7 vertebra involvement by the multiple myeloma; D and E: angio-CT in sagittal and coronal views demonstrating a displaced and virtually collapsed r-sided VA at the level of the tumor. VAS: Visual analogue scale; mJoA: modified Japanese Orthopedic Association scale; VA: Vertebral artery. Source: Author's case.

Figure 1. VA was encased and displaced by Multiple Myeloma.

VA is accompanied by two vertebral veins, which may be tamponed or coagulated as needed. Further exposure of VA can progress above or below as necessary (Figure 2). The VA runs parallel to the vertebral body at a distance of 5 to 10 mm, being displaced by the presence of tumors. In C2 and C3 areas, the VA first runs vertically for 5mm before horizontally entering the C3 TF, which is placed further laterally than the others. C2 transverse foramina, unlike the others, are obliquely oriented inferiorly and laterally.

The VA is in a free anatomical space, known as the intertransverse space, with no direct contact or adherence to the nerve root that crosses the posterior aspect of the VA obliquely from medial to lateral and superior to inferior. The nerve emerges behind the upper transverse process, crosses the VA in the space between the upper transverse process, and then runs down the lower transverse process's tip. To expose the nerve roots lateral to the VA, the longus capitis must be cut. The cervical nerve roots should not be mistaken for the tendons of the scalenus muscle, which are similar in appearance and run in the same oblique direction.

Anterolateral approach extensions

After controlling the VA, the lateral approach may be extended laterally to the brachial plexus and medially to expose the anterior wall of the vertebral bodies. The scalenus muscle may be detached from the tip of the transverse process to allow for a wider exposure of the tumor involving the brachial plexus. Behind the nerve roots are the subaxial joints, which may be reached by working between 2 nerve roots. As a result, tumors involving the cervical spine can be followed from the TF to the opposite lateral side by performing oblique osteotomies that expose and decompress the ventral dural sac.

To further widen the field between SM and IJV, the SM must be separated from the mastoid process at the CVJ in the exposure of the V3 segment of the VA.[9]

At this level, the fat layer filling the space between VA and IJV is separated from the deep cervical muscles after the accessory nerve is identified at its junction with SM. The nerve is exposed along its course from the SM to the jugular foramen. To protect the nerve during retraction, the fat layer is rolled around it. If the nerve is working above C2, it retracts inferiorly; if it is working below C1, it retracts superiorly.

The tip of C1 transverse process is palpated 15mm anterior and below the mastoid tip. The muscles are divided flush to the transverse process of C1, exposing the VA segment at C1-C2, the posterior arch of atlas, and the VA segment above C1. The C2 nerve root crosses perpendicularly to the C1-V1 V segment. The two VA segments are almost parallel to each other, with only the posterior arch of the atlas intervening. The C1 transverse can be similarly opened working subperiosteally to expose the entire VA. Then, VA can be transposed posteriorly, allowing direct access to the lateral wall of the upper cervical spine and cranio-vertebral junction, including the C2 body, C1-C2 joint, lateral mass of atlas, C0-C1 joint, the occipital condyle, and the jugular tubercle. Drilling C1-C2 joints and the lower part of the lateral mass of the atlas allows the body of C2, the odontoid, to be reached. Drilling C0-C1 joint leads to the tip of the odontoid and lower clivus. Superiorly, the jugular foramen may be opened on its inferior and posterior aspect by drilling the jugular tuberculum- the juxtacondylar approach, which exposes the jugular bulb. If the mastoid is resected, the sigmoid sinus is exposed, allowing access to the posterior fossa from a lateral perspective without the need to drill the petrous bone. The IX, X, and XI cranial nerves can be followed along their course in the neck, jugular foramen, and posterior fossa, after the dura is opened perpendicular to the sigmoid sinus.

When performing the anterolateral approach, the most common causes of morbidity are the leakage of lymph in the V1 segment, Horner's syndrome in the V2 segment, and accessory nerve (CN XI) pain or palsy in the V3 segment.

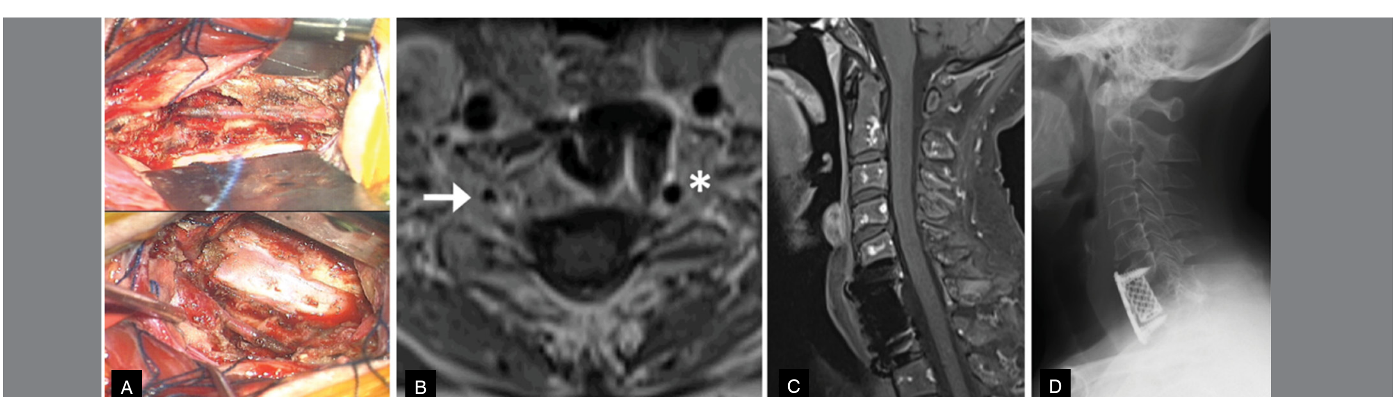
Posterolateral approach

For intradural lesions involving the V3 and V4 segments of the VA, the posterolateral approach (PLA), which is a posterior approach with lateral extension up to the occipital condyle, is appropriate.[10] The amount of condylar drilling necessary will depend on the degree of anterior extension in the case of bone tumors. The transcondylar technique is limited to drilling the posterior one-third of the condyle until it reaches the hypoglossal canal's cortical bone.

The patient is placed in the prone position with the head slightly flexed without compromising the venous return. A midline vertical or hockey stick incision is made to provide the necessary bone exposure, followed by posterior soft tissue dissection that exposes the occiput and posterior arch of the atlas up to the C0-C1 joint.

The superior suboccipital triangle, which contains the V3 segment of the VA and whose lateral limits are formed by the superior and inferior oblique muscles, can be identified by exposing the deep muscular planes. The lateral point of attachment on the C1 transverse process of this triangle allows for the identification of the C1 TF and the V3 lateral extent.

In the posterior arch of C1, the VA medial border is identified by a decrease in height of the arch. VA is lined caudally by the first cervical nerve root. Dissection of the superior and anterior portion of this segment is more delicate, as the periosteal sheath forms a fibrous adhesion with the atlanto-occipital membrane cranially, and with the capsule of the atlanto-occipital joint anteriorly. These structures may be cut; however, ossification or calcification make it more difficult. The VA venous plexus connects to the condylar vein, which can be coagulated, divided, or tamponed with bone wax and hemostatic agents at the bony canal. The inferior aspect of VA is easier to control because the periosteum of the posterior arch of the atlas is elevated from medial to lateral and its inferior edge



A: intraoperative views demonstrating the VA exposure after identification of its course anterior to C7 TF and skeletonization from TF of C6. Note the coagulation of the venous plexus around the vertebral artery to control bleeding. Vertebral body osteotomies to resect the bone tumor; B: T1-weighted axial MRI showing the patency of the R-sided VA occupying a normal position (arrow); C and D: T1-weighted MRI and lateral x-ray showing tumor removal and vertebral reconstruction with titanium mesh, plate, and screws. VA: vertebral artery; TF: transverse foramen. Source: Author's case.

Figure 2. Cervical Spine Multiple Myeloma.

towards the superior edge to reach the VA groove. In the event of sinus bleeding, hemostasis can be achieved by bipolar coagulation of the periosteal sheath. The VA is followed along its groove and from the end of the groove to the dura mater. On the other end, the groove is followed up to the transverse foramen. The distance from midline to the C1 TF is 25mm on each side, about twice the distance between midline and the medial end of the VA groove. At this stage, the whole V3 segment of VA can be mobilized and transposed superiorly or inferiorly, before the dura mater is incised to access the corticomedullary junction. A wider exposure of intradural tumors, even those anteriorly located, allows for safe tumor removal without considerable neuroaxis retraction.

Cervical spine stabilization

When making decisions about cervical spine instability caused by neoplastic lesions, the Spine Instability Neoplastic Score (SINS) is a useful tool.[11] Instability risk factors include C2 or C7 laminectomy, with corresponding muscle tension band insertion detachment from C2 and C7, and younger age. Direct indicators of instability include axial mechanical pain, kyphotic curve progression, and more than 2 mm translation in flexion-extension x-rays.

In cervical spine tumor pathology, the type of tumor, degree of osteotomy, and surgical technique all have an impact on spinal stability (Figure 2).[12,13] For dumbbell neurinomas located in the subaxial cervical spine, the anterolateral approach saves the facet joints, hence eliminating the requirement for lateral mass screw construct stabilization. Similarly, no instability results from adding an oblique corpectomy osteotomy to the ALA since the anterior longitudinal ligament and two-thirds of the vertebral body are preserved.

In the CVJ, spinal stability is secured by the preservation of the ligaments, primarily the transverse ligament, the anterior arch of C1, and the lateral and condylar masses. Resection of these elements, or destruction by the tumor, can thereby cause instability.

The majority of authors concur that it is safe to remove less than 50% of the occipital condyle.[14] For intradural tumors at the CVJ, there is rarely a need to drill any of the occipital condyle because the posterior limit of the condyle is anterior to the neural elements. In anteriorly located tumors, the neuroaxis is even pushed further posteriorly, opening the corridor for tumor excision. As a result, in the posterolateral approach, CVJ instrumentation is rarely required, minimizing the related morbidity. (Table 2)

Intra-operative VA injury

The most effective strategy to prevent VA injury is to gather as much information as possible from pre-operative imaging about the location and caliber of VA, followed by subperiosteal dissection of the periosteal sheath that encloses the VA and its venous plexus. (Table 2) Fortunately, the majority of the bleeding encountered is venous in origin, coming from the venous plexus surrounding the VA. A thorough and serene examination of the bleeding pattern will aid in the differential diagnosis of the cause of the hemorrhage.

In the event of bleeding, the anesthesia team should be notified to take the necessary procedures to ensure hemodynamic stability; the next best option is to use direct tamponade and hemostatic drugs. When direct primary vessel repair is feasible, it is the preferred method.[15]

If repair is not possible in a life-threatening condition, bleeding must be controlled via vascular ligation, which is often well tolerated. In all cases, the surgery should be followed by an early assessment with angiography or angio-CT to demonstrate vascular compensation and rule out vascular complications, such as hemorrhage or thromboembolism, dissection, stenosis, or pseudoaneurysm of the VA. Any VAI can cause the formation of a pseudoaneurysm weeks or months after the injury, with potentially lethal effects. These patients, consequently, require close short- and long-term follow-up in the postoperative period.

Secondary revascularization, vessel repair, or occlusion may be considered by endovascular stenting and coiling or bypass surgery.[16] Since any vascular wall lesion increases the risk of thrombosis or arterial dissection, aspirin should be added if it is assumed to be safe

CONCLUSIONS

Tumors that involve or encase the VA are substantially more difficult to resect radically, and they are more likely to cause post--operative morbidity. Optimizing tumor exposure, access, and vascular control can be achieved through a precise understanding of the surgical anatomy of the VA, its variations, and the different lateral approaches to the cervical spine and CVJ. It is important not to overlook thorough pre-operative planning that considers imaging data.

When *en bloc* resection is recommended for bone tumors, VA dissection should be tried because it is feasible in most situations. If it fails or is impossible, VA sacrifice should be considered based on balloon occlusion testing results.

When the VA is encased in the TF or seating on the bone groove of C1, VA subperiosteal dissection can be performed without significant risk of injury because it is surrounded by a venous plexus, both of which are enclosed by a continuous subperiosteal sheath that is continuous with the periosteum of the transverse foramina (TF) and foramen magnum dura mater. The presence of VA loops allows for the mobilization of the artery from the groove or foramen, resulting in vascular control and access to the pathology.

The anterolateral approach is suitable for intra- and extradural tumors from the CVJ to C7, whereas the posterolateral approach with VA transposition from the C1 arch allows wider exposure of intradural tumors. Depending on the extent of osteotomies performed for tumor access or resection and condyle preservation, no instrumentation is required for stabilization in most cases.

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REFERENCES

1. Peeters JB, Idriceanu T, El Hage G, Martin T, Salaud C, Champagne PO, Bojanowski MW. A comprehensive review of the vertebral artery anatomy. Neurochirurgie. 2024;70(3):101518. doi: 10.1016/j.neuchi.2023.101518.
2. Aoyama T, Obara N. Vertebral Artery Terminating Posterior Inferior Cerebellar Artery (PICA--VA) as a Potential Risk Factor in Cervical Spine Surgery. World Neurosurg. 2020;143:e535--e540. doi: 10.1016/j.wneu.2020.08.003.
3. George B, Blanquet A, Alves OL. Surgical exposure of the vertebral artery. Operative Techniques in Neurosurgery. 2001;4(4): 182-194. doi:10.1053/otns.2001.30169.
4. Bruneau M, George B. Foramen magnum meningiomas: detailed surgical approaches and technical aspects at Lariboisière Hospital and review of the literature. Neurosurg Rev. 2008;31(1):19-32; discussion 32-3. doi: 10.1007/s10143-007-0097-1.
5. Westbroek EM, Pennington Z, Ehresman J, Ahmed AK, Gailloud P, Sciubba DM. Vertebral Artery Sacrifice versus Skeletonization in the Setting of Cervical Spine Tumor Resection: Case Series. World Neurosurg. 2020;139:e601-e607. doi: 10.1016/j.wneu.2020.04.071.
6. Sorteberg A. Balloon occlusion tests and therapeutic vessel occlusions revisited: when, when not, and how. AJNR Am J Neuroradiol. 2014;35(5):862-5. doi: 10.3174/ajnr.A3852.
7. Yoon N, Shah A, Couldwell WT, Kalani MYS, Park MS. Preoperative embolization of skull base meningiomas: current indications, techniques, and pearls for complication avoidance. Neurosurg Focus. 2018;44(4):E5. doi: 10.3171/2018.1.FOCUS17686.
8. George B, Alves OL, Alexandre Carpentier A. The V1 and V2 segment of the vertebral artery: Surgery around the cervical vertebral bodies. Operative Techniques in Neurosurgery.2002;5(1):25-49. doi: 10.1053/otns.2002.0000.
9. George B, Blanquet A. The V3 segment of the vertebral artery. In: Pathology and surgery around the vertebral artery. Paris: Springer;2011.

10. George B, Lot G. Foramen Magnum Meningiomas: A Review from Personal Experience of 37 Cases and from a Cooperative Study of 106 Cases. Neurosurgery Quarterly. 1995;5(3):149-167.
11. Fourney DR, Frangou EM, Ryken TC, Dipaola CP, Shaffrey CI, Berven SH, et al. Spinal instability neoplastic score: an analysis of reliability and validity from the spine oncology study group. J Clin Oncol. 2011;29(22):3072-7. doi: 10.1200/JCO.2010.34.3897.
12. Noh SH, Takahashi T, Inoue T, Park SM, Hanakita J, Minami M, et al. Postoperative spinal deformity and instability after cervical spinal cord tumor resection in adults: A systematic review and meta-analysis. J Clin Neurosci. 2022;100:148-154. doi: 10.1016/j.jocn.2022.04.005.
13. Sciubba DM, Chaichana KL, Woodworth GF, McGirt MJ, Gokaslan ZL, Jallo GI. Factors associated with cervical instability requiring fusion after cervical laminectomy for intradural tumor resection. J Neurosurg Spine. 2008;8(5):413-9. doi: 10.3171/SPI/2008/8/5/413.
14. Shiban E, Török E, Wostrack M, Meyer B, Lehmberg J. The far-lateral approach: destruction of the condyle does not necessarily result in clinically evident craniovertebral junction instability. J Neurosurg. 2016;125(1):196-201. doi: 10.3171/2015.5.JNS15176.
15. Maughan PH, Ducruet AF, Elhadi AM, Martirosyan NL, Garrett M, Mushtaq R, et al. Multimodality management of vertebral artery injury sustained during cervical or craniocervical surgery. Neurosurgery. 2013;73(2 Suppl Operative):ons271-81; discussion ons281-2. doi: 10.1227/01.neu.0000431468.74591.5f.
16. An TY, Kang DH, Kim DH. Anastomosis and Endovascular Treatment of Iatrogenic Vertebral Artery Injury. Korean J Neurotrauma. 2021;17(2):204-211. doi: 10.13004/kjnt.2021.17.e28.