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Case Report

Management of complex vertebral artery anatomy in craniocervical surgery: A case report

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ABSTRACT

Background: The surgery on the craniocervical junction is associated with complex techniques that endanger the vertebral artery (VA), especially if there are some anatomical variations present, thereby increasing the risk of vascular injury, particularly during cervical decompression or instrumentation.

Case Description: A case of a 60-year-old female with progressive myelopathy and craniocervical junction malformation is presented. Key preoperative imaging findings included basilar invagination, C1 assimilation, and os odontoideum, along with VA anomalies such as a tortuous, hypoplastic left VA arising anomalously from the aortic arch and a right VA with a V2 segment forming a high-riding medial loop into the C2 vertebral body. The surgical procedure was performed through a posterior approach using C-arm fluoroscopy, Doppler ultrasound, and intraoperative neurophysiologic monitoring, which achieved adequate deformity fixation and anterior decompression.

Conclusion: Computed tomography angiography is the gold standard for assessing the preoperative VA anatomy at the craniocervical junction. Intraoperative Doppler ultrasound is invaluable because it minimizes the risk of sudden accidental injury to VAs in cases with abnormal anatomies.

Keywords: Cervical spine, Computed tomography angiography, Craniocervical junction, Doppler ultrasound, Vertebral artery

INTRODUCTION

The surgical management of cervical spinal stenosis with associated instability often necessitates ventral or dorsal decompression and instrumentation, procedures that carry a risk of vertebral artery (VA) injury.[1] The course of the VA is notably variable, with potential anomalies ranging from atypical V1 segment entrance in the subaxial spine to tortuosity of the V2 segment within the transverse foramina and displacement of the V3 segment from its typical position in the sulcus arteriosus of the C1 posterior arch.[11,14]

Evaluating transverse foramen morphology on computed tomography (CT) can raise suspicion for VA variants. Typically, as the VA ascends cranially, the transverse foramen shifts from an anterolateral to a posteromedial position.[12] Advanced preoperative imaging, particularly CT angiography (CTA), is recommended to delineate VA anatomy, identify variants, and prevent accidental injury during surgery.

The VA typically originates from the subclavian artery and is divided into four segments (V1-V4). The V1 segment extends from its origin to the C6 transverse foramen. The V2 segment courses through the transverse foramina of C6 to C2. The V3 segment begins as the artery exits the C2 transverse foramen and ends as it enters the dura mater, featuring a characteristic loop around the C1 lateral mass. The V4 segment is the intradural portion extending to the vertebrobasilar junction.[7] Variations in this course are common and can include abnormal origins and entrance levels, vessel diameter, and tortuosity. Of particular surgical relevance are high-riding VAs at C2, medial loops of the V3 segment, and anomalous courses between C1 and C2.[13] Recognition of these variations is crucial for safe surgical planning and execution in the craniocervical region.

Managing VA anomalies during craniocervical junction surgery presents unique challenges.[1] These variations can significantly impact surgical planning and increase the risk of vascular complications.

This case study presents a patient with complex craniocervical pathology and significant VA anomalies, emphasizing the critical role of preoperative planning and intraoperative precautions in surgical management. It highlights the importance of comprehensive preoperative imaging and intraoperative precautions in navigating complex VA anatomy during fixation.

CASE DESCRIPTION

Patient information

A female patient in her sixth decade presented to our specialist unit with progressive symptoms of cervical myelopathy, characterized by neck pain radiating to both arms, numbness, and gait instability over several months. Her past medical history is notable for type 2 diabetes mellitus, which required consideration during her evaluation and management.

Clinical findings

Neurological examination revealed a spastic gait, downbeat nystagmus, and muscle strength assessed at 4+/5 in the lower limbs and 3/5 in the upper limbs. Hyperreflexia was noted bilaterally, involving the biceps, brachioradialis, patellar, and Achilles tendons, accompanied by a positive Hoffman's sign, though clonus was absent.

Diagnostic assessment

Imaging studies

1. Craniocervical radiographs demonstrated atlantoaxial dislocation and basilar invagination on dynamic flexion/extension views [Figure 1]

Figure 1: (a) and (b) Preoperative Sagittal flexion and extension, cervical radiographs showing a craniocervical deformity inform of basilar invagination and C1- C2 mal-alignment and C1 assimilation.

2. CT scans revealed irreducible atlantoaxial dislocation, os odontoideum, basilar invagination, and C1 assimilation [Figures 2a and b]
3. Magnetic resonance imaging of the cervical spine showed severe central canal stenosis at C0-C1 and C1-C2 levels with associated spinal cord myelomalacia [Figure 2c]
4. CTA identified significant VA anomalies: (a) Left VA: Hypoplastic and tortuous, with abnormal origin directly from the aortic arch and entrance into the C5 transverse foramen. (b) Right VA: V2 segment forming a high-riding medial loop into the C2 vertebral body [Figure 3].

Therapeutic intervention

Surgical approach

Based on the complex anatomy, a posterior approach was planned for C1-C2 instrumentation, fusion, and foramen magnum decompression. The surgery was performed using intraoperative C-arm fluoroscopy, Doppler ultrasound, and continuous neurophysiological monitoring.

Management considerations

Based on the complex anatomy and imaging findings, several management strategies were considered:

1. Posterior approach (chosen): C1-C2 instrumentation, fusion, and foramen magnum decompression
2. Anterior approach: Rejected due to the presence of basilar invagination and potential difficulty in accessing the craniocervical junction.

The posterior approach was ultimately selected as the most appropriate strategy for this patient's anatomical challenges.

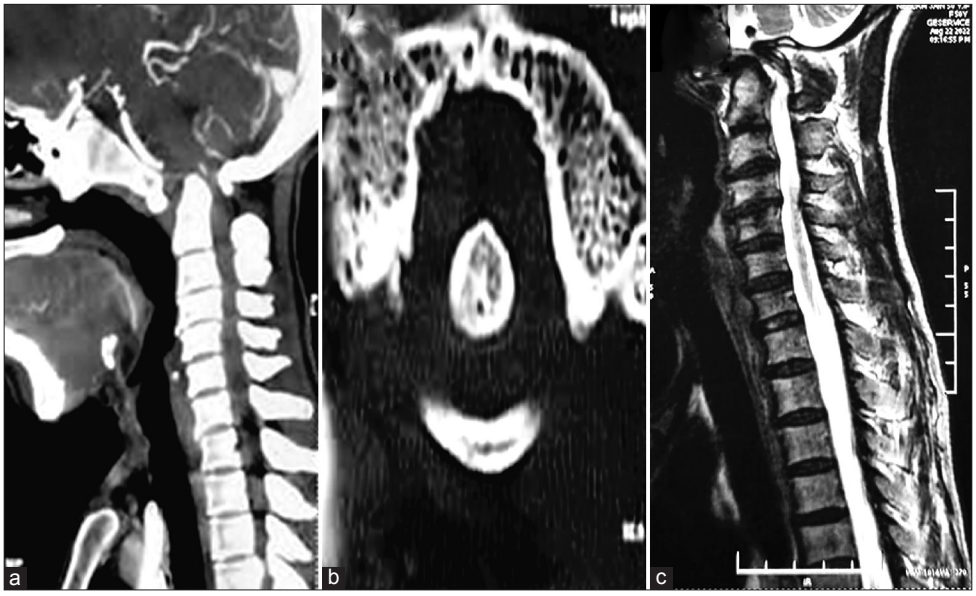

Figure 2: (a-c) Computed tomography scan of the cervical spine, sagittal and axial showing evidence of severe canal stenosis due to atlantoaxial dislocation and basilar invagination and assimilation of C1 is also noted. Sagittal magnetic resonance imaging of the cervical spine shows evidence of severe central canal stenosis at C1–2.

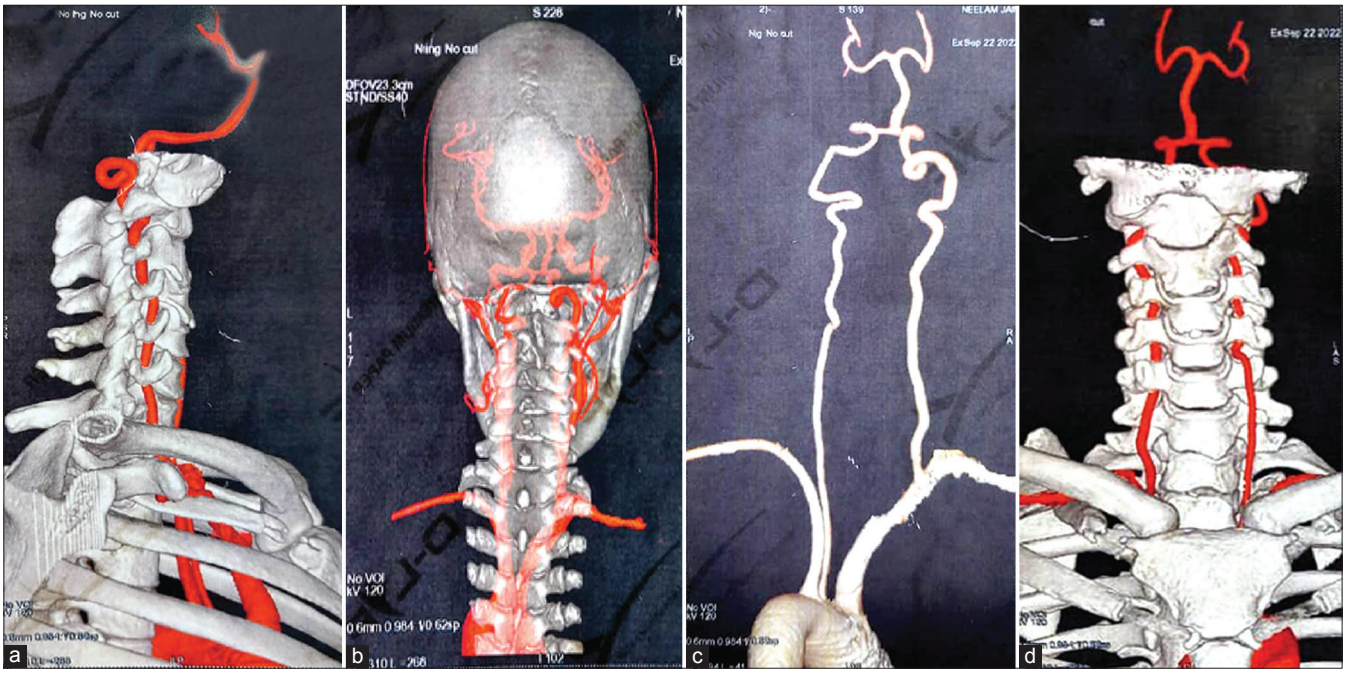

Figure 3: (a and b) Computed tomography angiography (CTA) scans show a right tortuous vertebral artery (VA) distal-V2 segment medialized into the C2 level. (c) CTA: Right VA V2 segment medial loop at C2. Left VA: Abnormal aortic arch origin, hypoplastic. (d) Left VA: Abnormal entrance into C5 transverse foramen.

Surgical procedure

1. The patient positioned prone with skull traction
2. C2 fixation: Left translaminar screw and right pars screw (trajectory adjusted due to medialized right VA)
3. C1 lateral mass screws placed bilaterally
4. Foramen magnum decompression performed
5. Structural allograft was placed in C1-C2 joint spaces after careful preparation and decortication of the articular surfaces.

6. Distraction and extension were applied before rod fixation
7. Intraoperative Doppler ultrasound confirmed the VA's position throughout the procedure.

Neurophysiological monitoring included somatosensory evoked potentials, motor evoked potentials, and electromyography of relevant muscle groups. Intraoperative challenges included careful dissection around the anomalous right VA at C2 and ensuring adequate decompression without compromising vascular integrity.

Follow-up and outcomes

Postoperative radiographs showed satisfactory correction of C1-C2 subluxation and reduction of basilar invagination [Figure 4]. The patient was discharged to rehabilitation on postoperative day 5. At 6-month follow-up, the patient demonstrated significant improvement in gait and upper extremity function. Neck pain had resolved, and repeat imaging showed stable instrumentation with evidence of fusion. The patient improved functionally 1-year postsurgery, with a near-complete resolution of myelopathic symptoms.

Figure 4: Postoperative sagittal cervical radiograph showing good correction of the C1–2 and basilar invagination reduction with instrumentations in place.

DISCUSSION

This case highlights the importance of thorough preoperative evaluation and surgical planning for craniocervical junction anomalies and VA variations. The patient presented with a complex constellation of findings, including basilar invagination, C1 assimilation, os odontoideum, and significant VA anomalies.

The variability in VA anatomy is well documented in the literature. Hong *et al*. reported VA entrance into the C6 transverse process in 94.9% of cases, with abnormal entrances at C4, C5, or C7 in 5.1%.[4] Bruneau *et al*. corroborated these findings, noting C6 entrance in 93% of specimens, with variations at C4 (1%), C5 (5%), and C7 (0.8%).[2] Our case demonstrated an even rarer variation, with the left VA originating directly from the aortic arch and entering at C5.

The upper cervical spine presents additional anatomical challenges, including persistent first intersegmental arteries, extracranial C1-C2 origin of the posterior inferior cerebellar artery, and VA fenestration.[9] A ponticulus posticus, a bony arch encircling the VA at C1, can further complicate surgical approaches.[5,6]

In our case, the right VA formed a high-riding medial loop into the C2 vertebral body, necessitating modification of the typical C2 pars screw trajectory. This underscores the importance of individualized screw trajectories based on patient-specific anatomy.

Table 1 summarizes the key anatomical variations encountered in this case and their corresponding surgical considerations.

Table 1: Key anatomical variations and surgical considerations.

Anatomical variation	Surgical consideration
Left VA: Hypoplastic, abnormal aortic arch origin, C5 entrance	Careful dissection on the left side, awareness of atypical VA course
Right VA: High-riding medial loop at C2	Modified C2 screw trajectory, use of translaminar screw on the left
Basilar invagination, C1 assimilation	Extended decompression, careful reduction technique
Os odontoideum	Stabilization of C1-C2, attention to potential instability

VA: Vertebral artery

Preoperative CTA and intraoperative Doppler ultrasound proved invaluable in navigating these anatomical challenges. These modalities allowed for precise localization of the VA throughout the procedure, minimizing the risk of vascular injury.

Intraoperative Doppler ultrasound proved crucial, allowing real-time localization of the anomalous VA throughout the procedure. This technique has been shown to reduce the risk of VA injury during cervical spine surgery, particularly in cases with anatomical variations.[3]

The posterior fixation approach is supported by literature showing favorable outcomes in patients with complex craniocervical junction anomalies.[10] However, the risk of VA injury remains a significant concern, with reported incidence ranging from 0.3% to 8.2% in cervical spine procedures.[8]

This case highlights the importance of tailoring surgical approaches to individual patient anatomy. The high-riding,

medial loop of the right VA at C2 necessitated modification of standard screw trajectories, emphasizing the need for flexible intraoperative decision-making based on preoperative imaging and intraoperative findings.

Strengths and limitations in our approach to this case

In this case, the approach's strengths included comprehensive evaluation by CT angio preoperatively, which helps examine complex VAs under vascular spatial surgery. Intraoperative Doppler ultrasound enabled localization of the arteries in real time, decreasing the chances of vascular injury. The care of the surgical team performed a proper evaluation, the decisions toward surgery were supported, and constant neurophysiological monitoring helped prevent cognitive complications through spinal cord and nerve protection. Limited generalizability of this kind of management is the particular weakness of the approach since such management was appropriate to a condition due to a rare anatomical sequence, which would not be the case for other cases.

CONCLUSION

This case exemplifies the complex interplay between osseous and vascular anatomy in craniocervical junction pathology. The variable course of the VA, particularly when tortuous or significantly displaced, poses substantial risks during both ventral and dorsal approaches to the cervical spine. Comprehensive preoperative imaging, including CTA, intraoperative Doppler ultrasound, and meticulous surgical planning, is essential in cases requiring atlantoaxial fixation or when suspicious transverse foramen morphology is identified. This approach enables surgeons to anticipate and navigate anatomical variations, thereby reducing the risk of VA injury during cervical spine surgery.

Future research should focus on developing standardized protocols for preoperative vascular evaluation in complex cervical spine cases and refining techniques for safe instrumentation in the presence of VA anomalies.

The primary "take-away" lessons from this case report

- Comprehensive preoperative imaging, including CTA, is essential to identify anatomical variations in the VA, which can significantly impact surgical planning and execution in craniocervical junction surgeries.
- Intraoperative Doppler ultrasound and neurophysiological monitoring are invaluable tools for safely navigating complex VA anatomy, helping to prevent accidental vascular injury during surgery.
- Tailoring surgical approaches to the patient's anatomy, especially in cases with significant VA anomalies, is crucial for achieving successful outcomes while minimizing potential complications.
- The integration of advanced imaging techniques and real-time intraoperative guidance can enhance the safety and effectiveness of procedures in patients with complex craniocervical pathologies.
- Thorough understanding and recognition of VA variations should be a key component of surgical education and training to prepare surgeons for the challenges posed by such anomalies.

Patient perspective

The patient appreciates the holistic approach of the whole process, which includes preoperative, operative, and postoperative phases, and mentioned appreciating explanations and consultations from the entire team. Assurance of safety during the operation was given through advanced images and technology. After the operation, the patient was much better, energetic, and had no neck pain anymore. The patient was satisfied with the fact that she actively participated in the decision-making process, as well as with the kind help of the doctors.

Authors' contributions

All authors conceptualized the study idea. Y.H.E. was part of the team and was responsible for reviewing and interpreting the radiographic images, confirming the anatomical variations, and was the major contributor to writing the manuscript. A.T. participated in the operative team, performed the surgical procedure, and contributed to writing the manuscript. Y.S.A. was in charge of the patient's overall care, led the surgical team, performed the operation, and contributed to writing the manuscript. All authors read and approved the final manuscript.

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Ethical approval

The Institutional Review Board approval is not required.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

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Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of Artificial Intelligence (AI)-Assisted Technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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