DOI: https://dx.doi.org/10.18203/issn.2455-4510.IntJResOrthop20260509

Original Research Article

Vertebral artery safe zone in anterior odontoid screw fixation

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Received: 18 December 2025
Revised: 03 February 2026
Accepted: 17 February 2026

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ABSTRACT

Background: Anterior odontoid screw fixation is a surgical technique for management of Type II odontoid fractures. The vertebral artery (VA) is located near odontoid process, making it more susceptible to injury during screw fixation. So, present study aimed to determine anatomical safe zone, which improves accuracy in screw fixation and enhances operative outcomes.
Methods: This observational study was conducted in the Department of Anatomy at All India Institute of Medical Sciences (AIIMS), Rishikesh, Uttarakhand, India. Total of 10 formalin-fixed cadaver necks were dissected. Inter-VA distances were measured from midline C2 to left and right sides of VA loops. Each measurement was repeated independently, and CT angiographic data were also analysed for comparison with cadaveric findings.
Results: Inter-VA distance in cadavers ranged from 28 mm to 36.1 mm, with a mean of 32.95±2.72 mm. The mean distance from the C2 midline to right VA loop was 15.61±1.25 mm, while left measured 17.24±1.80 mm, indicating a relatively wider zone on left side. CT angiographic measurements demonstrated narrower inter-VA distances (mean 25.3±3.29 mm), significant anatomical variability and differences between in-vivo and cadaveric assessments.
Conclusions: An accurate understanding of inter VA distance at the C2 level is critical for safe anterior cervical surgical approaches. Understanding these morphometric variations enables surgeons to anticipate high-risk areas and determine the optimal screw trajectory and size. As a result, pre-operative CT Angiography examination of the VA path is critical for reducing problems and ensuring optimal surgical outcomes at C2 level.

Keywords: Vertebral artery, Odontoid process, Anterior odontoid screw fixation, C2 vertebra, Safe surgical zone, Inter-vertebral artery distance

INTRODUCTION

The odontoid process (dens) of the axis is an important feature for atlantoaxial stability, serving as the pivot around which the atlas revolves. Fractures of the odontoid are common cervical spine injuries, especially in older patients after low-energy falls and in young people after high-energy trauma.[1] The Anderson and D'Alonzo categorisation method is still the most extensively used, with Type II fractures being the most unstable and surgically significant.[1]

Injuries like odontoid fractures and mixed atlas and axis fractures may include the axis vertebrae. According to previous research, odontoid process fractures are frequent, making around 10% to 20% of all cervical spine fractures. In type II odontoid fractures, posterior fusion carries a risk of harming the Vertebral Arteries and exiting nerve

roots.[2,3] According to a study on 116 injuries to the upper cervical spine, 31 of these lesions included both C1 and C2 fractures. These comprised 30% of C2 traumatic spondylolisthesis, 70% of atlas fractures, and 30% of odontoid fractures.[4]

Anterior odontoid screw fixation has gained popularity because it provides immediate stabilization, allows direct osteosynthesis, and preserves the physiological C1-C2 rotational motion.[5,6] However, the procedure is technically demanding, and the most feared complication is vertebral artery (VA) injury, which can lead to catastrophic hemorrhage, ischemia, or death.[7] The course of the VA at the base of the dens creates a narrow midline safe zone, making precise anatomical knowledge indispensable for surgeons.[8]

Previous studies have demonstrated significant variation in the inter-VA distance. Cadaveric studies such as those by Hasegawa et al. and Paramore et al. reported wider safe zones (17-20 mm), while radiological studies reported narrower measurements (13-15 mm).[2,3,9,10] Furthermore, ethnic and population-based differences have been highlighted, with Asian populations demonstrating narrower corridors compared to Western COHORTs.[2-4]

The present cadaveric study was undertaken to quantify the inter-VA distance at the anterior base of the dens in an Indian population, compare the results with existing anatomical and radiological studies, and discuss the implications for surgical safety during anterior odontoid screw fixation.

METHODS

The Department of Anatomy at the All India Institute of Medical Sciences (AIIMS) Rishikesh conducted this descriptive cross-sectional study from August 2014 to September 2015 with permission and approval from the Institutional Research and Ethical Committee, letter number, IEC/IM/111/RC60/2014. Ten adult male cadavers (20 sides) were used for a meticulous dissection of the VA along its entire length. The arteries underwent an injection of silicone before being painted red. Cadavers with gross cervical deformities, previous surgical interventions, or vascular disruption were excluded. The CT angiography and multiphasic contrast enhanced records of cervical spine from Department of Neurosurgery, were retrieved. The conditions like vasculitis and any abnormal growth that effect the normal architecture were excluded from the study.

Dissection

A standard anterior midline cervical approach was performed. Prevertebral soft tissues were removed, and both VA were carefully identified at the base of the dens Figure 1. The path and relationship of the VA after it leaves the transverse foramen C3 and continues upward was the main focus of this study (Figure 1c). Following the delineation of the bone landmarks and VA segments, the stepwise dissection was documented using measurements and pictures. CT angiographic image of C2 showing distance between inter-VA is depicted in Figure 2.

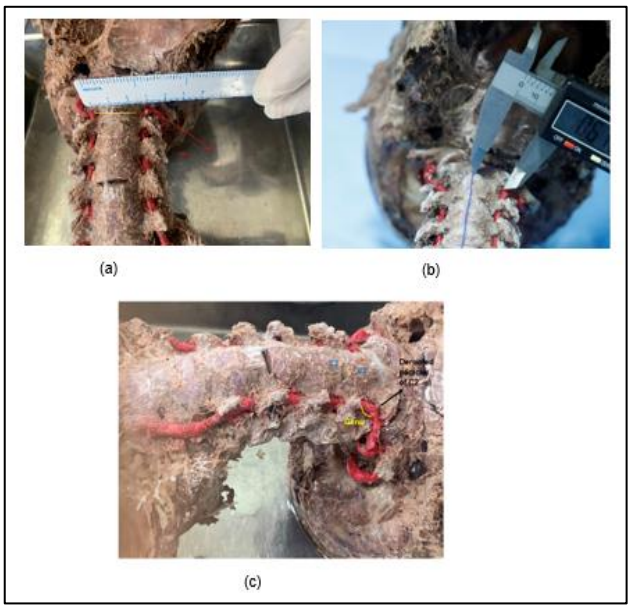

Figure 1: Course of vertebral artery and measurement of intervertebral distance; (a) distance between vertebral artery loops (inter VA Distance or safezone); (b) distance between C2 and vertebral artery loop); (c) after dissection, course of vertebral artery is visualized.

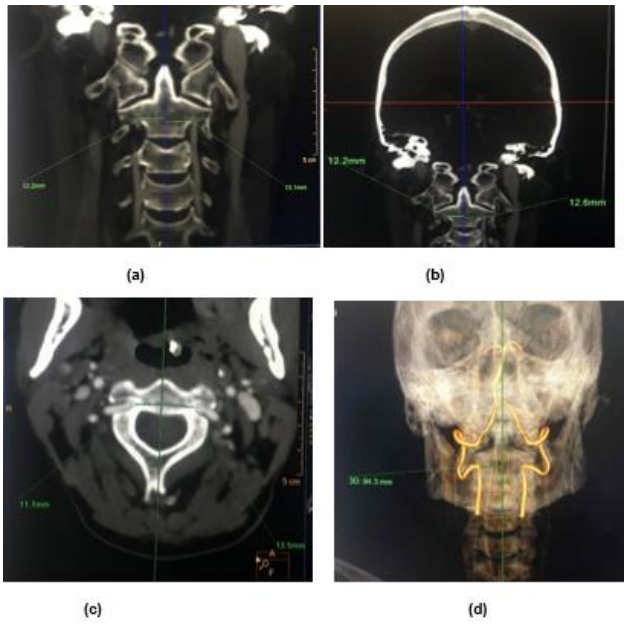

Figure 2: CT angiographic image of cervical spine showing distance between loop of right and left side vertebral arteries, (a): Coronal view (front to back slice), (b): Sagittal view (side to side slice), (c): Axial view (cross section), (d): 3D reconstruction image.

Measurements

The shortest inter-VA distance between the medial borders of the arteries at the anterior base of the dens and between C2 and VA loop was measured using digital Vernier calipers (Figure 1 a and b). Each measurement was performed twice independently by two observers, and the mean value was considered for analysis. For statistics, IBM SPSS statistics software was used.

Comparative analysis

The mean inter-VA distance obtained was compared with previous anatomical and radiological reports to assess differences in methodology, populations, and findings.

RESULTS

The distance of the tip (or dome) of the VA loop from the midline of the C2 body on the right, left, and the distance between right and left were measured by vernier callipers as shown in Figure 1 a and b.

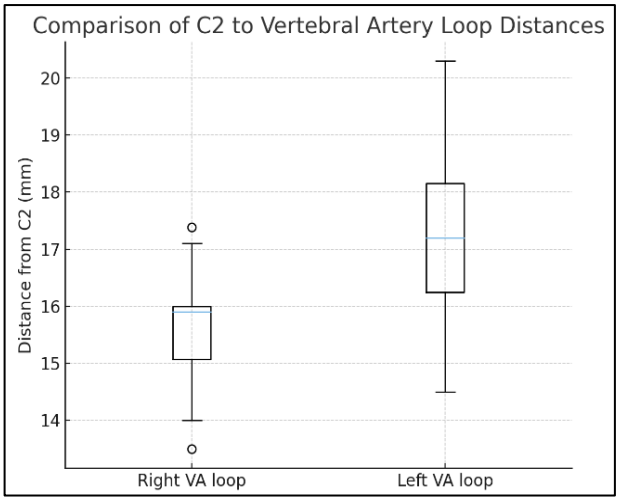

Figure 3: Comparison of C2 to right and left side of vertebral loop.

Right side (n=10): mean=15.61 mm, minimum=13.5 mm maximum=17.39 mm and standard deviation=1.22 mm; Left side (n=10): mean=17.34 mm, minimum=14.5 mm, maximum=20.3 mm and standard deviation (s)=1.90 mm.

Table 1: Different parameters of vertebral artery.

Parameter measured	Range (mm)	Mean±SD (mm)
Inter-VA distance (cadaveric study)	28-36.1	32.95±2.72
Inter-VA distance (CT angiography)	24-28	25.3±3.29
Distance from C2 midline to right VA loop	13.5-17.39	15.61±1.25
Distance from C2 midline to left VA loop	14.5-20.3	17.24±1.80
Medial-to-medial distance between VA loops (safe corridor)	28-36.1	32.95±2.72

Medial-to-medial distance between VA loops

The difference in the distance between VA loops in cadaveric study at the level of C2 and CT angiography indicates that there is notable anatomical variability in the transverse safe corridor available for anterior odontoid screw placement. The average space is sufficient for safe instrumentation, but the presence of narrow corridors (as low as 28 mm) emphasizes the need for preoperative imaging and careful intraoperative planning to avoid VA injury. The morphometric analysis revealed that the distance from C2 to the right VA loop is less as compared to left VA loop (Figure 3) (Table 1).

The medial-to-medial distance between VA loops measured 28 mm to 36.1 mm (mean 32.95±2.72 mm). These findings demonstrate that the left VA loop generally lies farther from the C2 midline compared to the right, contributing to a wider overall safe corridor. However, considerable variability, particularly in narrow corridors, highlights the importance of individualized morphometric assessment and preoperative imaging to minimize VA injury during anterior odontoid screw fixation.

DISCUSSION

Understanding the surgical anatomy of the VA and its relationship to the upper cervical vertebrae is crucial to avoid accidental injury during instrumentation.[11] Both anterior and posterior approaches can be used to approach the cervical spine. The anterior approach is mostly employed for lesions ventral to the spinal cord, whereas the posterior approach is used for lesions posterior or posterolateral to the spinal cord.[12,13] There is a risk of VA injury with both approaches. However, using an anterior cervical spine approach increases more risk.[12,13]

The incidence of VA injury while performing anterior cervical spine procedures has been reported as 0.22-2.77%.[12,13] Verbiest was the first to treat the injury of the VA.14 The VA damage during cervical spine decompression was documented for two cases of osteophytes and one case of tumours. MacDonnald et al reported one VA injury out of 36 corpectomy patients (2.77%), while Golfinos et al reported 0.3% VA injury in 1215 cases with the anterior cervical approach.[15,16]

In the present study mean distance between the C2 and right VA loop in cadaveric study is 15.6±1.25 mm while on the left side distance is 17.24±1.8 mm which is similar to the study conducted by Cacciola et al.[3] However, in contrast Güvençer et al conducted a study in which the distance between the VA's medial side of the V2 segment and the midline was 17.6±6.1 mm on the right and 14.7±2.1 mm on the left.[17] Cacciola et al found that the distance between the tip of the VA osseous segment and the midline of the C2 body ranged from 6.1 to 16.2 mm (11.7 mm average) from an anterior transoral surgical view.[3] Cruz-Elizondo et al measured 43.8±4.2 mm from the C2 spinous process to the medial margin of the proximal loop's most prominent point.[18] Mean distance between VA loops (safe window) in the present study is 32.95±2.72 mm which was similar to the study conducted by Cacciola et al and Guvencer et al.[3,17]

Mean inter VA distance in CT angiography in the present study is 25.3±3.29 mm and is similar to the study conducted by Watanabe et al, Cacciola et al and Guven et al.[2,3,19] Inter VA distance is more in the cadaveric studies as compared to radiological studies as muscle tone, vascular tone, and ligament tension are all lost in cadavers, particularly those that have been fixed in formalin. When the muscles, fascia, and sympathetic tone relax, the VA moves laterally. This extends the apparent inter-VA distance in cadaveric dissection.[3]

When doing anterior cervical spine surgery, it's important to consider the shorter distance between the VA and midline in the upper subaxial cervical spine. The shorter distance between the left and right VA in the upper subaxial cervical spine is attributed to the lower size of the vertebral bodies. The iatrogenic VA injuries most commonly arise from the movement of the decompression process to the lateral, because of the loosing of the midline by surgeon.[12,13] To avoid this risk, one requires some reference points for surgical orientation for e.g., the distance between the VA and a few landmarks, like the midline, the uncinate process, and the longus colli muscle.[17] Chronic ischaemia in VA areas can cause imbalance, motor coordination issues, dizziness, and vision disturbances. Iatrogenic injury or dissection of the VA can lead to a basilar stroke with poor outcomes.[20,21] Understanding the diversity and structural aspects of VA in different groups is crucial for understanding and predicting disease processes in the study area.[22]

In the study conducted by Khanfour et al average length of the vertical segment (C1 and C2) of VA was 9.7 mm on the right and 10.9 mm on the left.[23] According to Arthur et al the mean length of this segment was 9.8 mm on the right and 11.7 mm on the left.[24] The segment projected a variable distance laterally before climbing to the C1 transverse foramen, creating a loop. Placing C1-2 transarticular screws or C2 pars screws is likely to cause injury in the transition between the C1 and C2 vertical segments and the horizontal portion of the VA after exiting the C2 vertebral foramen.[23] The VA segment between the atlas and axis is laterally connected to the superior cervical sympathetic ganglion. According to Khanfour et al this gap is 1.4 mm on the right and 1.7 mm on the left.[23] According to Cacciola et al the genu of the VA lies between 0.6 and 4.8 (2.5 mm on average) from the articular surface of the SAF of the axis. The values measured ranged from 4.8 to 10.1 mm (7.33±2.15) on the right side and from 5.2 to 10 mm (7.14±2.31 mm) on the left.[3] We have not measured such findings in the present study.

Understanding the bones and surrounding anatomy is necessary as surgical techniques and instruments for treating unstable cervical spines are continuously progressing. When developing a surgical approach, the relationship between the C1-C2 vertebrae and the VA is crucial. Cervical instability has been treated with a variety of methods, including interspinous wiring, lateral screw and plate fixation, and interlaminar clamp and hook plating. One of the most advanced techniques available today for treating atlas and axis instability is transpedicular screw fixation. Screw fixation has become more common in recent years as a treatment for dens axis fractures. Transpedicular screws have been used to treat significant laminectomies, spinal trauma, and neoplasm-induced bone element degradation. During insertion, pedicle screws may injure the VA beneath the superior facets of the axis.[25] The potential risk of VA damage is a major disadvantage of atlantoaxial transarticular screw fixation particularly when using a high-riding style.[26] Additionally, there is a higher chance of VA damage with C2 pedicle screws or transarticular atlantoaxial screws, which are technically demanding.[27] Therefore, it is crucial that surgeons operate within a safe area, particularly for anterior pedicle, pars, posterior transarticular screw fixation, and screw fixation for odontoid fractures screws, in order to prevent VA injury even in the absence of angiography.[28]

CONCLUSION

An accurate understanding of the inter VA distance at the C2 level is critical for safe anterior cervical surgical approaches. A shorter medial distance between the VA increases the risk of iatrogenic injury during odontoid screw implantation, transoral exposure, and anterior decompression procedures. Radiological measures, which are smaller and more indicative of in-vivo anatomy, give an accurate reference for determining the true safe corridor for instruments. Understanding these morphometric variations allows surgeons to anticipate high-risk architecture and establish the best screw trajectory and size. As a result, pre-operative CTA examination of the VA path is critical for reducing problems and ensuring optimal surgical outcomes at the C2 level.

Funding: No funding sources
Conflict of interest: None declared
Ethical approval: The study was approved by the Institutional Ethics Committee

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Cite this article as: Malhotra R, Devi B, Sharma U, Arora R, Kandwal P, Singla M. Vertebral artery safe zone in anterior odontoid screw fixation. Int J Res Orthop 2026;12:416-20.