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RESEARCH ARTICLE

Posterior Exposure of the Vertebral Artery in the Subaxial Cervical Spine: A Cadaveric Study

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ABSTRACT

Vertebral artery anomalies and anatomic variations noted from cadaveric dissections and imaging studies are well documented within the literature at the craniovertebral junction as well as subaxial cervical spine. Such abnormalities can lead to Vertebral artery injuries causing a myriad of comorbidities for patients. In such situations, Vertebral artery may need to be repaired especially if the dominant artery was injured. In this study, we describe a safe surgical approach to expose the Vertebral artery in the subaxial cervical spine using 6 formalin fixed cadavers to assess the feasibility of our approach. Neural foraminal decompression was performed to identify the nerve roots followed by complete resection of the inferior and superior articular processes at the intended levels. The pedicle was skeletonized, and the posterior wall of the transverse foramen was removed. The Vertebral artery could then be exposed between the two nerve roots. Multiple measurements were reported to guide the approach, including the Vertebral artery diameter between the nerve roots on the left and right side from C3-C7, the distance from midline to the medial edge of the Vertebral artery, and the distance from midline to the lateral edge of the Vertebral artery. To our knowledge, this is the first study describing a safe approach to expose the subaxial Vertebral artery.

Key words: Vertebral Artery; Cervical Spine; Transverse Foramen.

Introducution

The vertebral artery (VA) travels through the transverse foramen of the cervical C1-C6 vertebrae. This vessel can have marked tortuosity and anomalies in its course such as intrusion into the vertebral bodies, which if ignored can lead to vertebral artery injury (VAI) during cervical spine procedures especially when coupled with posterior craniovertebral or subaxial cervical instrumentation. Early techniques, such as the Gallie Fusion, avoid the VAs at this level but at the expense of structure stability and with high nonunion rates. Later techniques, like the Magerl and Harms techniques, improved fusion rates but with VAI rates as high as 8% for Magerl and 5% for Harms[1]

Vascular anomalies involving the vertebral artery (VA) must also be meticulously avoided during procedures involving atlantoaxial dissection and lateral mass screw placement. Furthermore, there are specific scenarios in which penetrating injuries, such as gunshot wounds or blunt trauma as seen in facet dislocations, can lead to vertebral artery injury (VAI) and subsequent substantial bleeding may occur. In cases of tumor resection, especially when the tumor has enveloped the artery, the likelihood of VAI during the resection is high. Surgeons should be well-prepared to manage and control any bleeding from the vertebral artery if such an event arises. In such intricate situations, it's advisable to consider preoperative planning for embolization of the non-dominant vertebral artery. However, if injury occurs to the dominant vertebral artery, immediate repair becomes imperative.

When dissecting into the subaxial cervical spine, the V2 segment of the VA is of anatomical concern[2] Imaging analysis has been done to help identify which patients may be at risk of injury given their other skeletal anomalies. The artery may need be exposed and ligated/repaired in cases of pre or intraoperative injury to the artery. VA anomalies and anatomic variations noted from cadaveric dissections and imaging studies are well documented within the literature[3,4] at the craniovertebral junction as well as subaxial cervical spine[5]

To our knowledge, there is a scarcity of comprehensive anatomical documentation concerning the landmarks necessary for posterior dissection in the subaxial cervical spine, particularly in relation to the V2 segment of the vertebral artery (VA). Our primary objective was to establish reliable landmarks for a secure operative window, utilizing insights gained from cadaveric dissections. This approach aims to effectively reduce the potential for harm to both the cervical nerve root and the vertebral artery in the subaxial cervical spine. Our intention was to elucidate the precise and secure surgical measures aimed at mitigating the potential for iatrogenic injury to the artery during the exposure process.

Methods

Between June 2019 and May 2020, 6 skeletally mature formalin-fixed cadaver cervical spines were dissected and exposure of bilateral C2-C7 nerve roots was obtained. During dissection, each specimen was fixed in a surgical position for a posterior approach to the cervical spine. After identifying the boundaries of our surgical window, clinical photographs were taken and registered with the Image J software (1.52v National Institutes of Health) and measurements were obtained. The measurements were calibrated according to the number of pixels per millimeter of a known distance (10mm white square).

Surgical Approach

A midline incision was made and deepened down to the spinous process. The supraspinous and interspinous ligaments were left intact. The lamina of C2 to C7 were exposed and traced to the lateral mass (Figure 1 and 2). The lamina and the spinous process were removed using Rongeurs and Kerrison Rongeurs. Using the small Kerrison Rongeurs, the posterior wall of the cervical neuroforamen was excised. This was done by first resecting the inferior articular process (IAP) of the vertebrae above to expose the articular surface of the superior articular process (SAP) of the inferior vertebrae. The neuroforamen can be identified by putting a small, curved probe in the foramen. The SAP was resected using number 1 or 2 Kerrison Rongeur and was done with care so not to injure the nerve root or its sheet. Further resection of the SAP was performed to the superior edge of the pedicle below. The remaining portion of the IAP was also resected to expose the inferior edge of the vertebrae above. At this point, the nerve root was exposed and protected (Figure 3 and 4). The same process was followed for the levels above and below at the subaxial cervical spine. The posterior wall of the transverse foramen was also resected using the Kerrison Rongeur to expose the VA residing within it. Given that the VA runs anterior to the nerve roots, the posterior wall of the VA was able to be identified between the nerve root above and below. We also opened the dura to look at the anatomy of the cervical nerve roots for further delineation of the anatomy (Figure 5 and 6).

- The following measurements were analyzed at each level:
- The VA diameter between the nerve roots on the left and right side from C3-C7
- The distance from midline to the medial edge of the VA
- The distance from midline to the lateral edge of the VA

We evaluated for trends between specimens at the same level and trends between descending levels of the same specimen. We used ANOVA and Student's t-test to compare the means; a $p < 0.05$ was considered statistically significant.

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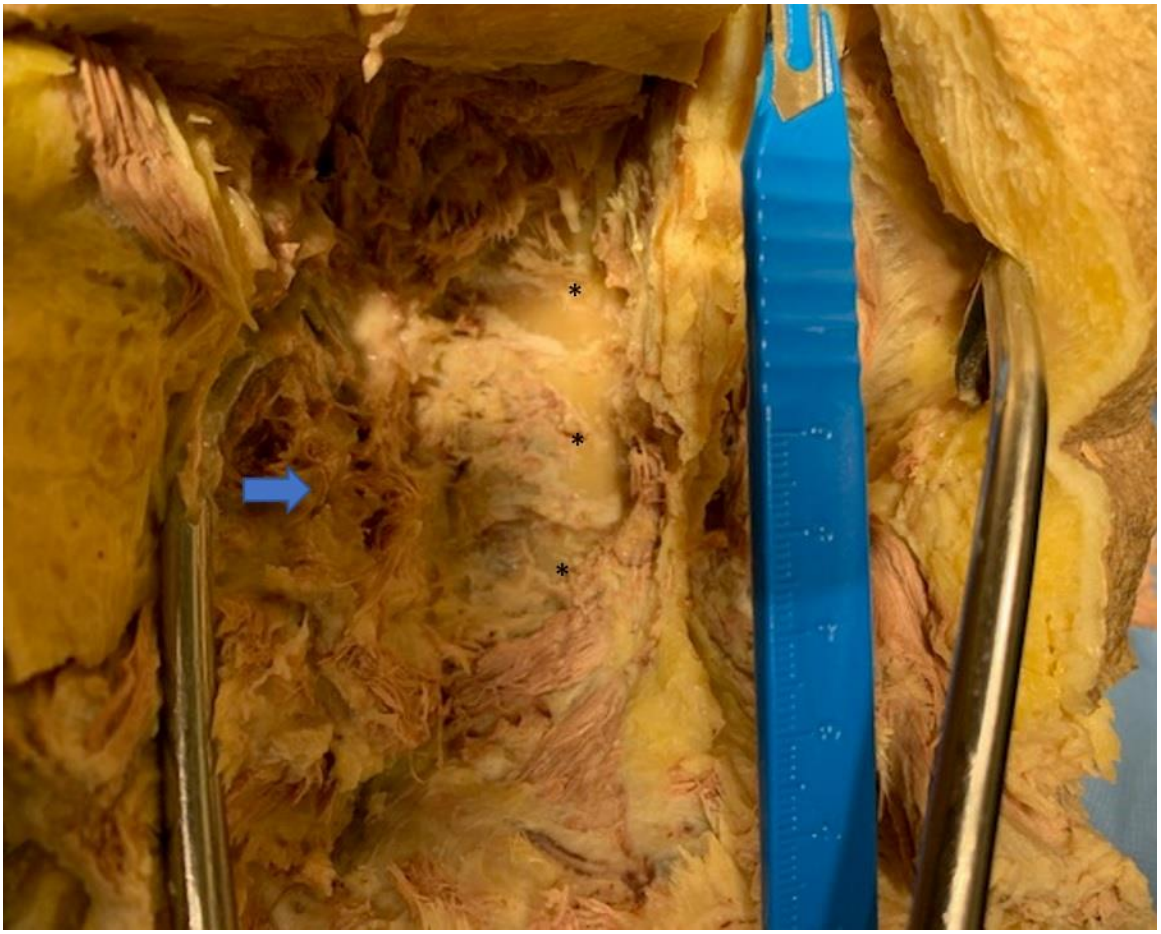

Figure 1. Shows the initial dissection after removal of the paraspinal muscles. *: Lateral mass of the cervical vertebrae, blue arrow: spinous process.

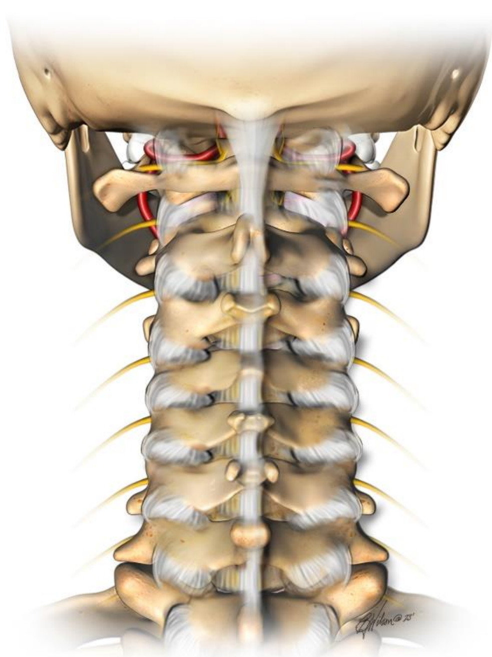

Figure 2: Shows the initial dissection after removal of the paraspinal muscles.

Figure 3. Shows the specimen after the removal of the lamina, facet joints and the pedicle. The small black arrows point to the nerve roots, the large black arrow points to the vertebral artery and the Asterix points to the dura.

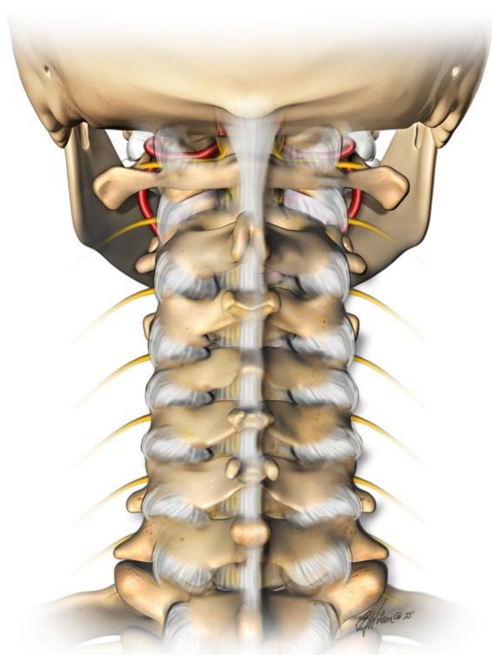

Figure 4. Shows the cervical rootlets and the position of the vertebral artery after removal of the dura membrane

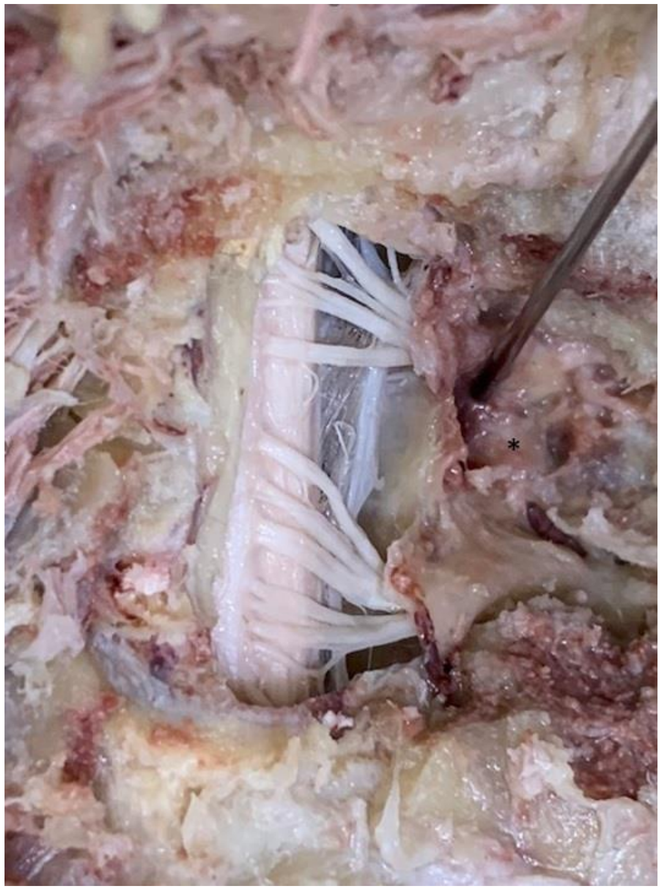

Figure 5. Shows the cervical rootlets and the position of the vertebral artery after removal of the dura membrane. Asterix points to the vertebral artery.

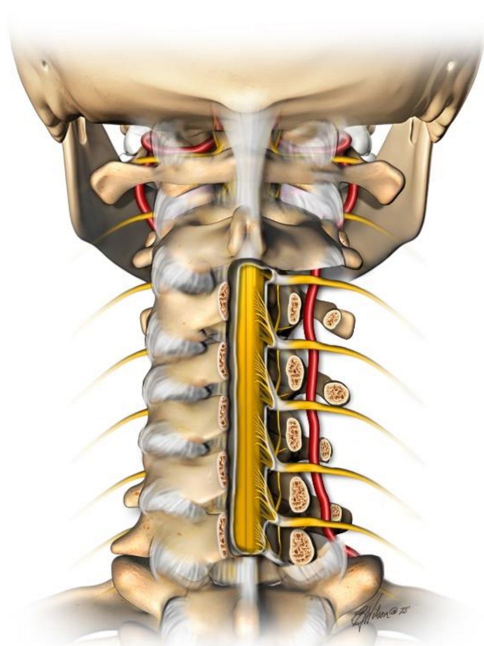

Figure 6. Shows the cervical rootlets and the position of the vertebral artery after removal of the dura membrane

Results

Table 1 shows the distance of the medial edge of the VA from the midline in millimeters (mm) at each level. There was no statistical difference between the right and the left side (P values are provided in the table). When measuring the distance of the lateral edge of the VA from the midline (in mm) at each level, there was also not any statistically signficiant difference between the right and the side (Table 2). On average the medial edge of the VA could be found 12-16 mm from the midline, which showed increasing trend from C3 to C7. The lateral edge of the artery was approximately 16-21 mm from the midline with increasing trend from cephalad to caudal, though these trends did not reach statistical significance (Table 4). The diameter of the artery also increased without statistical significance between the right and left and cephalad to caudal (Table 3 and 4). However, there was a statistically significant difference in the VA diameter between C2 and C3 (p=0.045), between C5 and C6 (p=0.014), between C6 and C7 (p=0.014) and between C7 and C8 (p=0.004), representing an overall increase in VA diameter from cephalad to caudal.

Table 1. Shows the distance of the medial edge of the vertebral artery from the midline in millimeters (mm) at each level. STD: Standard Deviation

Level	Right (mean + STD)	Left (mean + STD)	P value
C2	14.05 +/- 4.99	12.89 +/- 3.98	0.38
C3	13.34 +/- 3.92	13.54 +/- 5.19	0.55
C4	13.3 +/- 4.39	16.52 +/- 7.85	0.22
C5	15.48 +/- 6.11	16.95 +/- 7.42	0.745
C6	14.65 +/- 4.45	15.65 +/- 7.14	0.29
C7	16.15 +/- 5.84	15.8 +/- 7.63	0.72

Table 2. Shows the distance of the lateral edge of the vertebral artery from the midline in millimeters (mm) at each level. STD: Standard Deviation

Level	Right (mean + STD)	Left (mean + STD)	P value
C2	18.49 +/- 5.77	16.50 +/- 4.36	0.25
C3	18.27 +/- 4.11	18.6 +/- 6.07	0.33
C4	18.67 +/- 5.35	21.56 +/- 8.66	0.44
C5	20.3 +/- 6.17	21.67 +/- 8.68	0.48
C6	21.15 +/- 4.74	20.54 +/- 8.36	0.36
C7	21.41 +/- 5.67	20.67 +/- 8.72	0.38

Table 3. Shows the diameter of the vertebral artery in millimeters (mm) at each level. STD: Standard Deviation

Level	Right (mean + STD)	Left (mean + STD)	P value
C2	3.88 +/- 1.28	3.17 +/- 1.08	0.66
C3	3.24 +/- 0.8	3.41 +/- 0.64	0.92
C4	3.05 +/- 0.57	3.1 +/- 0.92	0.59
C5	4.01 +/- 0.86	3.72 +/- 0.42	0.09
C6	4.29 +/- 0.68	3.83 +/- 0.63	0.64
C7	4.68 +/- 1.5	3.91 +/- 1.15	0.56

Table 4. Compares the distance of the medial edge of the vertebral artery from the midline and diameter of the vertebral artery in millimeters (mm) at each level. STD: Standard Deviation

Level	Distance of the medial edge of the vertebral artery from the midline	Diameter of the vertebral artery
C2	13.42 +/- 4.31	3.5 +/- 1.19
C3	13.44 +/- 4.39	3.32 +/- 0.69
C4	14.76 +/- 6.09	3.07 +/- 071
C5	16.14 +/- 6.42	3.88 +/- 0.68
C6	15.19 +/- 5.83	4.04 +/- 0.67
C7	15.97 +/- 5.53	4.3 +/- 1.33
P value	0.75	0.02

Discussion

The incidence of VA injuries is 0.07% in cervical spine surgery and is most likely to occur during posterior instrumentation of the cervical spine at a rate of 32.4% of all VAIs at this level[6]. In the subaxial cervical spine, the vertebral artery (VA) finds itself encased within the confines of the transverse foramen. This unique anatomical placement necessitates significant bone resection for the purpose of exposing the artery. A paramount consideration in cervical spine approaches is to minimize the inherent risks associated with potential injuries to the spinal cord, nerve roots, and the VA itself. The preservation of the VA assumes a pivotal role in maintaining the blood supply to the intricate structures of the brainstem, encompassing the pons, medulla, and midbrain. Housed within this brainstem territory are the nuclei of the cranial nerves that regulate essential functions such as swallowing, hearing, balance, taste, speech, and both motor and sensory innervation of the face. While occurrences of such injuries are infrequent, their potential consequences can be profound, even extending to brainstem strokes. The dense concentration of cranial nuclei in this region gives rise to an array of syndromes that have been identified, including Ondine's syndrome, One and a half syndrome, top of the Basilar syndrome, Claude syndrome, Brissaud-Sicard syndrome, Gaperini Syndrome, and Locked-in Syndrome, among others. These syndromes highlight the intricate and delicate nature of this region and underscore the significance of safeguarding the VA during surgical interventions[7]. In general brainstem strokes constitute 10% of the all brain strokes and have poor prognosis, thus highlighting the essential need to preserve and protect its blood supply.

Previous studies have investigated the VA and its segments in relation to various landmarks as well as pedicle width and the minimum and maximum pedicle transverse angles[2] to help determine a beacon by which to proceed with craniovertebral dissection and fusions. We aimed to find a consistent anatomical landmark in the subaxial cervical spine to serve as a guide during posterior surgical exposure and fusion procedures in order to assist with decreasing the risk of VAI.

Our study revealed that there was no significant discrepancy in the distance of the vertebral artery (VA) from the midline when comparing the right and left sides. Additionally, our findings did not indicate any variance in diameter between the left and right VAs. At a distance of approximately twelve to fifteen millimeters from the midline, surgeons should anticipate encountering the artery, which typically exhibits a diameter of 3-4 millimeters. As outlined in Table 4, the artery's diameter demonstrated a gradual decrease from the caudal to cranial regions. This observation could potentially affect the risk of VA injury in the caudal levels. This aspect holds particular importance while the surgeon navigates the process of removing the superior articular process (SAP) and conducting dissections around the cervical nerve root.

Our previous study on 64 cadavers on safe exposure of the VA through anterior cervical spine approach showed that the distance of the medial edge of the artery increases from cranial to caudal: 13.3 +/- 2.2 at C2 and 13.2 +/- 1.2 at C3 which increased to 19.9 +/- 3.9 at C7[8]. Güvençer et al. also demonstrated that the medial edge of the artery is at the minimum 8 mm from the midline. Similar to our previous study, the diameter of the VA increased from cephalad to caudal, though it did not reach statistical significance[3]. Additionally, we found that the artery gets closer to the midline as it ascends in the cervical spine. Other important points in VA exposure are the tortuosity and appearances of the artery, especially in the 4th and 5th interspace where there is 20% chance of such anomalies occurring, which can potentially result in injuries of the artery during exposure[8]. Other studies with larger number of specimens showed that from C3 to C7 the distance of the VA to the midline increases. This distance increase from almost 13 mm to 20 mm but it's almost always more than 8 mm[8]. Although the diameter of the VA changes most of the previous studies did not show any significant difference among different cervical levels.[3,8,9]. This is due to the variability of the VA diameter that no significant changes could be discerned. The VA can also show tortuosity and has been proven to correlate with degeneration of the cervical spine. This might be due to the fact the VA is fixed to the nerve root by a fibro ligamentous band and collapse of the disc causes tortuosity of the artery. This tortuosity is mostly found in the 4th and the 5th levels up to 43% of the specimens[8]. Prior to the exposure of the artery CT and MRI images should be reviewed to mitigate the risk of injury to the artery during exposure.

In the posterior approach to the vertebral artery (VA), utilizing nerve roots strategically can serve as a protective mechanism against potential injuries, given their posterior positioning in relation to the VA. An illustrative technique that exemplifies the exposure of cervical nerve roots is cervical neuroforaminal decompression, which is frequently employed for treating upper extremity radiculopathies. This technique involves the use of a high-speed burr to meticulously remove approximately 50% of the medial facet, encompassing both the superior and inferior articular processes. This procedure effectively exposes the nerve root. Subsequently, the removal of the entire inferior articular process becomes feasible, facilitated by the safeguard provided by the superior articular process shielding the nerve root. Delicate utilization of a small Kerrison Rongeur permits the removal of the superior articular process while ensuring the nerve root's protection.

This sequence of steps leads to comprehensive exposure of the nerve root, extending from the pedicle above to the pedicle below. By replicating these steps at adjacent levels, the posterior wall of the transverse foramen comes into view, with the pedicle positioned medially. To further enhance access, the delicate wall of the transverse foramen can be cautiously removed using the method mentioned earlier, ultimately revealing the VA. Alternatively, an approach involving the direct exposure of the artery in the space between the nerve roots is possible. However, it's worth noting that mobilizing the nerve roots could potentially offer increased accessibility to the artery, thus optimizing the surgical exposure process.

The key factor in exposure of the VA through posterior approach is identification of the nerve roots. Unlike to an anterior approach, the posterior approach results in the presence of the nerve roots posterior to the VA. In the anterior exposure of the artery, we previously demonstrated that the transverse process (TP) can be safely used to prevent VA damage[10]. For the medial to lateral approach, dissecting in line with the level of the upper vertebral end plate leads to the tip of the TP. Staying 2 mm above and below the mid axis of the TP while following the TP angle (almost 10 degrees) will expose the entire TP. Removal of the TP with Kerrison Rongeur will then expose the anterior aspect of the VA[10].

Limitations of the Study

The use of formalin fixed cadavers rather than fresh cadavers reduces the pliability of the soft tissues and require additional techniques to mobilize the soft tissues, which may have potentially impacted our measurements. Additionally, the power of the study would strengthen by increasing the number of cadavers used thus making our findings more generalizable.

Conclusion

During exposure of the V2 segment of the VA during the subaxial C spine, use of known distances from midline, as well as identification of the cervical nerve root can assist with minimizing the risk of injury to the VA.

Conflict of Interest Statement:

There is no conflict of interest regarding this article among the authors.

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It is a cadaveric study, so no IRB, patient consent or ethical approval was necessary.

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