

Morphometric Analysis of the Transverse Foramen of Atlas and Its Implications for the Vertebral Artery: A Computed Tomography Study

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Abstract

Background: The transverse foramen of the atlas transmits the vertebral artery and is of critical importance during craniovertebral junction surgeries. Variations in its morphology may predispose the vertebral artery to iatrogenic injury.

Aim: To analyze the morphometry and anatomical variations of the transverse foramen of the atlas using computed tomography and to assess their clinical implications for vertebral artery safety.

Materials and Methods: A retrospective cross-sectional CT-based study was conducted on 120 adult cervical spine CT scans. Bilateral anteroposterior and transverse diameters of the transverse foramen were measured. Side-wise and sex-wise comparisons and the presence of accessory transverse foramina were evaluated. Statistical analysis was performed using SPSS version 25.0.

Results: The mean transverse diameter was 6.42 ± 0.84 mm on the right and 6.89 ± 0.91 mm on the left ($p = 0.001$). The mean anteroposterior diameter was 5.21 ± 0.73 mm on the right and 5.67 ± 0.79 mm on the left ($p = 0.003$). Asymmetry was observed in 39.2% of cases. Accessory transverse foramina were identified in 15% of subjects.

Conclusion: Significant morphometric variability and asymmetry exist in the transverse foramen of the atlas. Preoperative CT evaluation is essential to reduce the risk of vertebral artery injury during craniovertebral junction surgeries.

Keywords: Atlas; Transverse foramen; vertebral artery; Computed tomography; Craniovertebral junction.

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Introduction

The atlas (C1 vertebra) plays a pivotal role in maintaining stability and facilitating mobility at the craniovertebral junction. One of its most clinically significant anatomical features is the transverse foramen, which transmits the vertebral artery along with accompanying veins and sympathetic nerve plexus.

The vertebral artery is particularly vulnerable during procedures such as C1 lateral mass screw fixation, posterior cervical instrumentation, and decompressive surgeries at the craniovertebral junction. Variations in the size, shape, and symmetry of the transverse foramen may alter the course or caliber of the vertebral artery, thereby increasing the risk of iatrogenic injury.

Although classical anatomical descriptions provide a general overview of the transverse foramen, population-specific morphometric data remain limited. With the increasing use of computed tomography (CT) for preoperative planning,

radiological morphometric analysis allows precise, reproducible assessment of osseous landmarks.

The present study aims to analyze the morphometry and anatomical variations of the transverse foramen of the atlas using CT imaging and to highlight their implications for vertebral artery safety during craniovertebral junction surgeries.

Materials and Methods

Study Design and Setting: This retrospective cross-sectional study was conducted in the Department of Anatomy in collaboration with the Department of Radiology at a tertiary care teaching hospital.

Study Sample: A total of 120 CT scans of the cervical spine of adult subjects were included in the study.

- Males: 68
- Females: 52

- Age range: 18–75 years
- Mean age: 46.3 ± 12.4 years

Inclusion Criteria

- Adults aged ≥ 18 years
- Normal craniovertebral junction anatomy
- High-quality CT images suitable for morphometric analysis

Exclusion Criteria

- Cervical spine trauma
- Congenital vertebral anomalies
- Degenerative, neoplastic, or infectious pathology
- History of cervical spine surgery

Imaging Technique

- Multidetector CT scans were obtained using a standard cervical spine protocol.
- Slice thickness: 1.0 mm
- Axial sections with multiplanar reconstructions
- Measurements were performed using inbuilt workstation digital calipers

Parameters Measured

- Transverse (mediolateral) diameter
- Anteroposterior diameter
- Side-wise symmetry
- Presence of accessory transverse foramina

Ethical Considerations: Institutional Ethics Committee approval was obtained. Patient anonymity and confidentiality were strictly maintained.

Statistical Analysis: Data were analyzed using SPSS version 25.0. Results were expressed as mean \pm standard deviation.

Side-wise comparisons were performed using paired t-test and sex-wise comparisons using independent t-test. A p-value < 0.05 was considered statistically significant.

Results

Morphometric Measurements

- Transverse diameter (mm): Right 6.42 ± 0.84 ; Left 6.89 ± 0.91 ; $p = 0.001$
- AP diameter (mm): Right 5.21 ± 0.73 ; Left 5.67 ± 0.79 ; $p = 0.003$

Side-wise Asymmetry: Asymmetry of the transverse foramen was observed in 47 cases (39.2%), with the left side being larger in 25.8% and the right side in 13.4% of subjects.

Sex-wise Comparison: Males demonstrated significantly larger transverse foraminal dimensions compared to females ($p < 0.05$).

Accessory Transverse Foramen: Accessory transverse foramina were identified in 18 subjects (15%), occurring unilaterally in 10% and bilaterally in 5% of cases.

Morphometric measurements of the transverse foramen of the atlas are summarized in Table 1. Statistically significant side-wise differences were observed.

Table 1: Morphometric measurements of the transverse foramen of atlas (in mm)

Parameter	Right (Mean \pm SD)	Left (Mean \pm SD)	p-value
Transverse diameter	6.42 ± 0.84	6.89 ± 0.91	0.001*
Anteroposterior diameter	5.21 ± 0.73	5.67 ± 0.79	0.003*

* $p < 0.05$ considered statistically significant

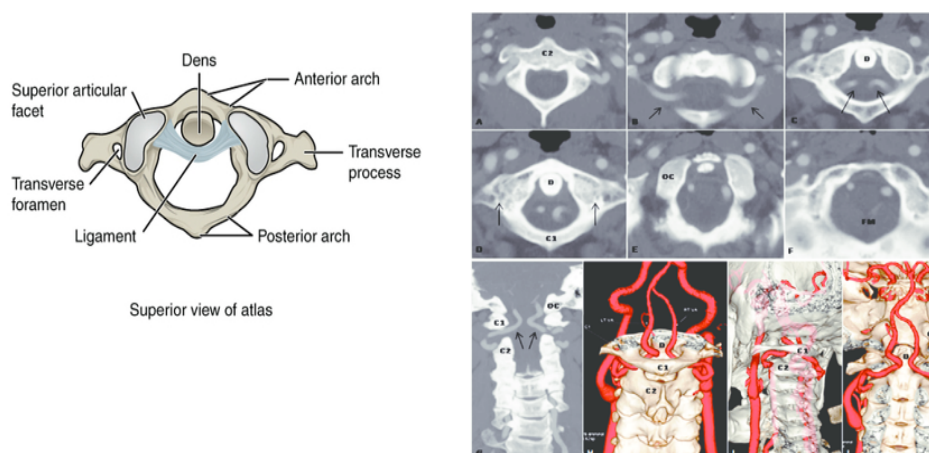


Figure 1: Axial CT image of atlas showing measurement of transverse and anteroposterior diameters of the transverse foramen.

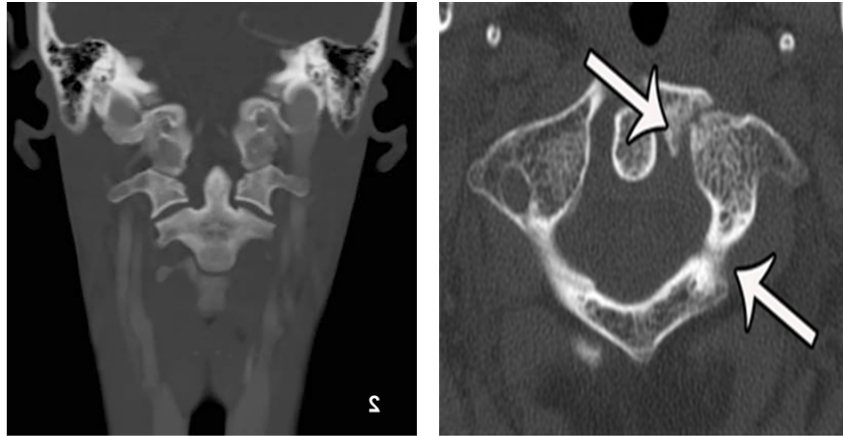


Figure 2: Coronal CT reconstruction showing bilateral transverse foramina and side-wise asymmetry.

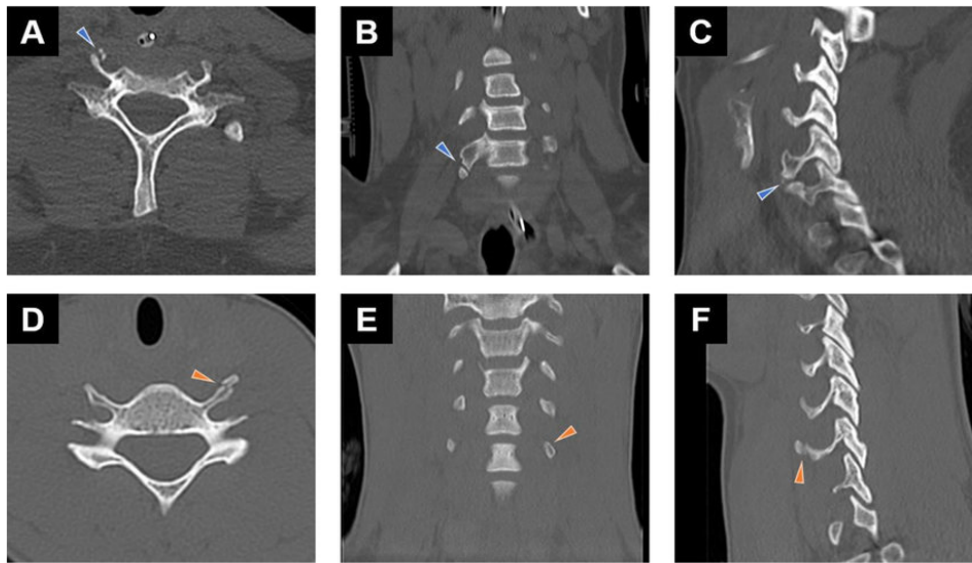


Figure 3: Axial CT image showing accessory transverse foramen of atlas.

Discussion

The present CT-based morphometric study demonstrates significant variability in the dimensions of the transverse foramen of the atlas. The left transverse foramen was significantly larger than the right, supporting the concept of left-sided vertebral artery dominance reported in earlier studies. Nearly 40% of subjects exhibited asymmetry, emphasizing the importance of individualized preoperative evaluation. Such variations are particularly relevant during C1 lateral mass screw placement, where unrecognized anatomical differences may result in catastrophic vertebral artery injury.

Accessory transverse foramina were observed in 15% of cases, a finding of substantial clinical significance. These foramina may transmit duplicated vertebral arteries or anomalous venous channels. The findings of this study align with previous radiological and osteological studies, while contributing valuable population-specific data.

Clinical Significance

- Provides morphometric data essential for safe craniovertebral junction surgery.
- Helps identify anatomical risk factors for vertebral artery injury.
- Useful for anatomists, radiologists, neurosurgeons, and spine surgeons.

Limitations

- Retrospective study design.
- Lack of CT angiographic correlation.
- Single-center study population.

Conclusion

The transverse foramen of the atlas exhibits significant morphometric variability and side-wise asymmetry. Detailed preoperative CT evaluation is strongly recommended.

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