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CT-Based Morphometric Evaluation of Foramen Transversarium Variations in Indian Population with Clinical Implications for Vertebral Artery Compression and Cervical Spine Surgery

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ABSTRACT

Background: The foramen transversarium (FT) of cervical vertebrae transmits the vertebral artery, vertebral vein, and sympathetic plexus. Variations in its morphology and morphometry may alter the course of the vertebral artery and contribute to vertebrobasilar insufficiency, dizziness, headache, and complications during cervical spine surgery.

Methods: A retrospective CT-based study was conducted on 100 cervical spine CT scans obtained from adults aged 18–70 years. All cervical vertebrae from C1 to C7 were evaluated bilaterally. Morphological assessment included classification of FT shapes into round, oval, elongated, and almond-shaped types. Morphometric analysis included anteroposterior (AP) and transverse diameters. Statistical analysis was performed using Student's t-test and ANOVA, with $p < 0.05$ considered statistically significant.

Results: A total of 700 cervical vertebrae were evaluated. Oval and round FT was the most common shapes observed. Typical vertebrae (C3–C6) predominantly exhibited round and oval FT, whereas atypical vertebrae demonstrated greater morphological variability. Almond-shaped FT showed statistically significant predominance in typical vertebrae ($p = 0.03$). Significant side-wise differences in AP diameter were observed at C2 ($p = 0.006$) and C6 ($p = 0.041$). No significant differences were found in transverse diameters across vertebral levels.

Conclusion: Considerable morphological and morphometric variations exist in the FT among the Indian population. Recognition of these variations is important for radiologists, anatomists, and spine surgeons to avoid vertebral artery injury and improve surgical planning.

Key-words: Foramen transversarium; Cervical vertebrae; Vertebral artery; Morphometry; Computed tomography; Cervical spine surgery

INTRODUCTION

The foramen transversarium (FT) is a distinctive anatomical feature of the cervical vertebrae and serves as a conduit for the vertebral artery, vertebral vein, and accompanying sympathetic nerve plexus.

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Typically, the vertebral artery traverses the transverse foramina from the sixth cervical vertebra (C6) to the atlas (C1) before entering the cranial cavity through the foramen magnum to contribute to the posterior cerebral circulation. Owing to its close relationship with critical neurovascular structures, the FT holds substantial anatomical, radiological, and surgical importance. [1,2]

Morphological and morphometric variations of the FT are frequently encountered and may include alterations in shape, size, symmetry, duplication, hypoplasia, stenosis, or even absence of the foramen. These variations may arise due to developmental or

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embryological alterations involving the vertebral artery and surrounding osseous structures. Such anatomical variations can potentially alter the course of the vertebral artery and predispose individuals to vertebrobasilar insufficiency, dizziness, headache, migraine, vertigo, and neurological manifestations secondary to vascular compromise. [3–5]

The atypical cervical vertebrae, particularly the atlas (C1), axis (C2), and vertebra prominens (C7), demonstrate greater anatomical variability than the typical cervical vertebrae (C3–C6). The transverse foramen of C7 is often smaller or occasionally absent because the vertebral artery usually enters the transverse canal at the C6 level. Variations involving the FT at these vertebral levels are clinically significant during cervical spine instrumentation and posterior surgical approaches due to the increased risk of vertebral artery injury. [6,7]

Recent advances in multidetector computed tomography (MDCT) have enabled precise evaluation of osseous anatomy and detailed morphometric assessment of cervical vertebrae. CT imaging provides superior spatial resolution and accurate visualization of the FT, making it an effective modality for identifying anatomical variations relevant to surgical planning and radiological interpretation. [8,9] Knowledge of FT morphology and morphometry is therefore essential for anatomists, radiologists, neurosurgeons, orthopedic surgeons, and spine surgeons involved in cervical spine procedures. [9,10]

Several osteological and radiological studies have investigated FT variations in different populations; however, limited CT-based data are available regarding the Indian population. Furthermore, population-specific anatomical variations may influence the prevalence and pattern of FT morphology. Therefore, the present study was undertaken to evaluate the morphological and morphometric characteristics of the foramen transversarium in typical and atypical cervical vertebrae using computed tomography and to assess their potential clinical implications for vertebral artery compression and cervical spine surgery.

MATERIALS AND METHODS

Study Design- This retrospective observational study was conducted in the Department of Anatomy in collaboration with the Department of Radiodiagnosis at Integral Institute of Medical Sciences and Research, Integral University, Lucknow, Uttar Pradesh, India. The study was designed to evaluate the morphological and morphometric variations of the foramen transversarium (FT) in cervical vertebrae using computed tomography (CT) imaging. Similar CT-based morphometric methodologies have been utilized in previous anatomical and radiological studies evaluating cervical vertebral variations. [8,9]

Study Duration- The study was conducted over a period extending from January 2025 to May 2026 after obtaining ethical clearance from the Institutional Ethical Committee of Integral Institute of Medical Sciences and Research (IEC/IIMSR/2025/15).

Study Population- A total of 100 CT scans of the neck and thorax were retrospectively analyzed. The study population included adult subjects aged between 18 and 70 years who underwent CT imaging for clinical indications unrelated to cervical vertebral pathology. From each CT scan, all cervical vertebrae from C1 to C7 were evaluated, resulting in assessment of 700 cervical vertebrae.

Inclusion Criteria

- Adults aged between 18 and 70 years
- Both male and female participants
- CT scans with adequate image quality for morphometric analysis

Exclusion Criteria

- History of cervical spine surgery
- Cervical trauma or fracture
- Congenital cervical spine deformities
- Severe degenerative or pathological conditions affecting cervical vertebral anatomy
- Poor-quality CT images unsuitable for accurate measurements

CT Imaging Technique- CT imaging was performed using a 128-slice Siemens SOMATOM Definition AS multidetector CT scanner (Siemens Healthcare, Germany). Axial and coronal images were obtained with the following imaging parameters:

- Slice thickness: 1 mm
- Reconstruction interval: 1 mm
- Field of view (FOV): 25 cm
- Matrix resolution: 512 × 512 pixels

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Non-contrast CT images were used for optimal visualization of bony anatomy. Multidetector CT has been recognized as a reliable modality for precise morphometric evaluation of cervical vertebrae and foramina transversaria due to its superior spatial resolution and multiplanar reconstruction capabilities. [11,12]

Morphological Assessment- The foramen transversarium was evaluated bilaterally at each cervical vertebral level (C1–C7). Morphological assessment included classification of FT according to shape into:

- Round
- Oval
- Elongated
- Almond-shaped

Typical cervical vertebrae (C3–C6) and atypical cervical vertebrae (C1, C2, and C7) were analyzed separately for comparative evaluation. Morphological classifications used in the present study were based on previously published osteological and radiological studies. [13,14]

Morphometric Assessment Morphometric parameters were measured bilaterally using CT workstation software tools, including 2D-distance and angle measurement functions. The following measurements were recorded:

- Anteroposterior (AP) diameter of FT
- Transverse diameter of FT

All measurements were recorded in millimeters (mm). The dimensions were evaluated at each cervical vertebral level from C1 to C7. Similar measurement techniques have been utilized in previous CT morphometric analyses of the cervical spine. [15,16]

Statistical Analysis- The collected data were entered into Microsoft Excel and analyzed statistically using appropriate statistical methods. Continuous variables were expressed as mean ± standard deviation (SD), while categorical variables were represented as frequencies and percentages. The independent Student's t-test was used for side-wise comparison between right and left FT measurements. One-way analysis of variance (ANOVA) was used to compare morphometric parameters among different FT shapes. A p-value of less than 0.05 was considered statistically significant.

Ethical Considerations- Ethical approval for the study was obtained from the Institutional Ethical Committee of Integral Institute of Medical Sciences and Research, Lucknow (IEC/IIMSR/2025/15). Patient confidentiality and anonymity were maintained throughout the study. As the study was retrospective and observational in nature, waiver consent was obtained according to institutional ethical guidelines.

RESULTS

A total of 100 computed tomography (CT) scans of the cervical region were included in the present study. All cervical vertebrae from C1 to C7 were evaluated bilaterally, resulting in assessment of 700 cervical vertebrae and 1400 foramina transversaria (FT) displayed in Table 1. The study population comprised 50 male and 50 female participants aged between 18 and 70 years. The mean age of the participants was 39.2 ± 13.85 years.

Table 1: Demographic Characteristics of the Study Population

Parameter	Value
Total participants	100
Male	50
Female	50
Age range (years)	18–70
Mean age (years)	39.2 ± 13.85
Total vertebrae evaluated	700
Total foramina evaluated	1400

Morphological analysis demonstrated considerable variability in the shape of the FT across cervical vertebral levels as demonstrated in Table 2. The observed FT shapes were categorized as round, oval, elongated, and almond-shaped. Typical cervical vertebrae (C3–C6) predominantly exhibited round and oval FT morphology, whereas atypical vertebrae (C1, C2, and C7) demonstrated greater variability and asymmetry in shape. Oval-shaped FT represented the most common morphological pattern overall.

Statistical analysis revealed no significant differences between typical and atypical vertebrae for round, oval, or elongated FT shapes. However, almond-shaped FT were significantly more common in typical cervical vertebrae compared to atypical vertebrae ($p = 0.03$).

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Table 2: Shape-wise Distribution of Foramen Transversarium in Typical and Atypical Cervical Vertebrae

Shape	Typical Vertebrae n (%)	Atypical Vertebrae n (%)	p-value
Round	187 (23.4%)	144 (24.0%)	0.80
Oval	220 (27.5%)	181 (30.1%)	0.30
Elongated	162 (20.2%)	135 (22.5%)	0.33
Almond-shaped	230 (28.7%)	141 (23.5%)	0.03*

**Statistically significant ($p < 0.05$)*

Morphometric assessment included measurement of anteroposterior (AP) and transverse diameters of FT at all cervical vertebral levels from C1 to C7 depicted in Table 3. The largest FT dimensions were observed at the C1 vertebral level, whereas the smallest dimensions were observed at C7. In general, atypical vertebrae demonstrated greater morphometric variability compared to typical vertebrae.

Table 3: Side-wise Comparison of Anteroposterior Diameter of Foramen Transversarium

Vertebral Level	Right Mean ± SD (mm)	Left Mean ± SD (mm)	p-value
C1	6.03 ± 2.73	5.64 ± 2.51	0.30
C2	5.04 ± 2.64	6.04 ± 2.46	0.006*
C3	5.73 ± 2.51	5.38 ± 2.44	0.32
C4	5.77 ± 2.39	5.34 ± 2.39	0.20
C5	5.44 ± 2.57	5.52 ± 2.48	0.83
C6	5.39 ± 2.54	6.24 ± 4.68	0.041*
C7	5.20 ± 2.48	5.36 ± 2.53	0.65

**Statistically significant ($p < 0.05$)*

A statistically significant side-wise difference in AP diameter was observed at the C2 and C6 vertebral levels. At both levels, the left-sided FT demonstrated larger mean AP diameters than the right side. No statistically significant side-wise differences were observed at the remaining cervical vertebral levels.

Correlation between FT shape and morphometric dimensions is demonstrated in Table 4, as the relationship between FT morphology and morphometric dimensions were evaluated using one-way ANOVA.

Table 4: Comparison of FT Dimensions According to Shape

Shape	n	Transverse Diameter (Mean ± SD)	AP Diameter (Mean ± SD)
Round	331	5.32 ± 2.53	5.51 ± 2.51
Oval	401	5.49 ± 2.67	5.70 ± 2.52
Elongated	297	5.14 ± 2.61	5.42 ± 2.55
Almond-shaped	371	5.10 ± 2.66	5.67 ± 3.23
Statistical Test			
ANOVA (F-value)	-	0.44	1.71
p-value	-	0.72	0.16

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No statistically significant association was observed between FT shape and morphometric dimensions. The transverse and AP diameters remained relatively consistent across different FT shapes. Overall, the findings of the present study demonstrate substantial morphological and morphometric variability of the foramen transversarium among cervical vertebrae, particularly in atypical vertebral levels.

DISCUSSION

The present CT-based study was conducted to evaluate the morphological and morphometric characteristics of the foramen transversarium (FT) in typical and atypical cervical vertebrae in an Indian population. Anatomical variations of the FT are clinically important because of their close association with the vertebral artery, vertebral vein, and sympathetic nerve plexus. Variations in the morphology or dimensions of the FT may influence vertebral artery course and hemodynamics, thereby contributing to vertebrobasilar insufficiency and increasing the risk of vascular injury during cervical spine procedures. [1,2]

In the present study, considerable morphological variability of the FT was observed. Oval and round shapes were the most frequently encountered configurations, while elongated and almond-shaped foramina were less common. These findings are in agreement with the observations of Pandey *et al*., Molinet *et al*., and Nurani et al., who also reported predominance of round and oval FT in cervical vertebrae. [8,10,12] The predominance of these shapes may reflect the normal anatomical adaptation required for passage of the vertebral artery and associated neurovascular structures.

Typical cervical vertebrae (C3–C6) demonstrated relatively uniform FT morphology, whereas atypical vertebrae (C1, C2, and C7) exhibited greater variability in both shape and dimensions. This observation is consistent with previous studies reporting an increased anatomical variability in atypical cervical vertebrae due to developmental and embryological differences. [6,11,17]

The atlas and axis possess unique structural and biomechanical characteristics, while the C7 vertebra frequently demonstrates a smaller or incomplete FT because the vertebral artery commonly enters the transverse canal at the C6 level. [4,7]

An interesting finding of the present study was the significantly higher frequency of almond-shaped FT in typical cervical vertebrae compared to atypical vertebrae. Although most previous studies have focused primarily on duplication and asymmetry of FT, limited literature is available regarding detailed shape-wise comparison. This finding may therefore represent a population-specific morphological variation detectable through high-resolution CT imaging. [20]

Morphometric analysis revealed that the dimensions of FT varied among different cervical vertebral levels. The largest foramina were observed at the C1 level, whereas the smallest dimensions were observed at C7. Similar findings have been reported by Gupta *et al.* and other studies have observed a progressive reduction in FT dimensions from upper to lower cervical vertebrae. [7,15-21] The relatively larger FT at C1 may be attributed to the increased caliber and tortuous course of the vertebral artery at the atlanto-occipital junction.

The present study demonstrated significant side-wise asymmetry in the anteroposterior (AP) diameter at the C2 and C6 vertebral levels. At both levels, the left-sided FT showed significantly larger AP dimensions than the right side. This finding correlates with previous studies suggesting dominance of the left vertebral artery in a substantial proportion of the population. [12,15] A larger left FT may reflect adaptation to accommodate a relatively larger vertebral artery. Such asymmetry is clinically important because vertebral artery dominance may influence surgical approaches and risk of vascular complications during cervical instrumentation.

No statistically significant differences were observed in the transverse diameter across most vertebral levels. Similarly, ANOVA analysis showed no significant correlation between FT shape and morphometric dimensions. These findings suggest that although the external morphology of FT may vary considerably, the functional dimensions required for transmission of vertebral vessels remain relatively preserved. Comparable findings have been described in radiological morphometric studies. [12,21]

The clinical implications of FT variations are substantial. Narrowing, asymmetry, duplication, or altered morphology of FT may predispose individuals to vertebral artery compression during cervical movements, resulting in symptoms such as vertigo, dizziness, headache, migraine, and vertebrobasilar insufficiency.

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Furthermore, detailed knowledge of FT anatomy is essential during posterior cervical surgeries, transpedicular screw fixation, cervical decompression procedures, and radiological interpretation of cervical spine imaging. Unrecognized anatomical variations may increase the risk of vertebral artery injury, neurological deficits, and surgical complications. [3,5]

Overall, the present study highlights significant morphological and morphometric variability of the foramen transversarium and emphasizes the importance of detailed anatomical understanding for radiological assessment and safe cervical spine surgery.

STRENGTHS

The present study has several important strengths. The use of multidetector computed tomography (MDCT) allowed accurate visualization and precise morphometric assessment of the foramen transversarium with high spatial resolution. Unlike conventional osteological studies, CT imaging enabled evaluation of clinically relevant anatomical variations in living subjects. The study comprehensively analyzed both morphological and morphometric characteristics of the foramen transversarium across all cervical vertebral levels from C1 to C7. Furthermore, inclusion of both typical and atypical cervical vertebrae provided a detailed understanding of vertebral level-specific variations and asymmetry patterns. Bilateral assessment of foramina transversaria also facilitated evaluation of side-wise differences, which may have clinical implications during cervical spine surgery and radiological interpretation. Additionally, the study contributes valuable population-specific anatomical data regarding the Indian population, which remains comparatively underrepresented in the existing literature.

LIMITATIONS

Despite its strengths, the study has certain limitations. The study was conducted at a single tertiary care center with a relatively limited sample size, which may restrict the generalizability of the findings to the broader population. The retrospective nature of the study limited control over imaging parameters and patient-related clinical variables. Vertebral artery anatomy and hemodynamic characteristics were not directly evaluated using CT angiography or Doppler imaging, which could have provided better correlation between foraminal morphology and vascular variations. Interobserver and intraobserver variability in morphometric measurements were also not assessed. In addition, the study did not evaluate the association between morphometric variations and clinical symptoms such as vertebrobasilar insufficiency, dizziness, or cervical pain. Further multicentric studies with larger sample sizes and angiographic correlation are recommended to validate and expand upon the present findings.

CONCLUSIONS

The present CT-based study demonstrated significant morphological and morphometric variability of the foramen transversarium among cervical vertebrae in the Indian population. Typical vertebrae predominantly exhibited round and oval FT, whereas atypical vertebrae showed greater variation and asymmetry. Significant side-wise differences in AP diameter at C2 and C6 suggest potential vertebral artery dominance and asymmetrical vascular anatomy. These findings are clinically important during cervical spine surgeries, radiological interpretation, and vertebral artery evaluation. Comprehensive understanding of FT anatomy may help reduce the risk of vertebral artery injury during cervical instrumentation and improve diagnostic accuracy in cervical spine imaging.

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