

Evaluation of Normal Anatomy and Anatomical Variations of Foramen Transversarium by Multidetector Computed Tomography

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Abstract:

Background: The foramen transversarium (FT) is a critical anatomical structure of the cervical vertebrae, transmitting the vertebral artery, vein, and sympathetic nerve fibers. Variations in its morphology can have significant clinical implications, particularly in surgical and radiological contexts. This study aimed to assess the normal anatomy and anatomical variations of the FT using multidetector computed tomography (MDCT).

Material and Methods: This cross-sectional observational study was conducted over one year at Indira Gandhi Institute of Medical Sciences (IGIMS), Patna. A total of 100 adult patients aged 18–70 years underwent cervical spine MDCT for various clinical indications. The images were reviewed independently by two radiologists to classify FT morphology at cervical levels C1–C7. FT variations were documented based on symmetry, accessory foramina, and dimensions. Descriptive statistics were applied to assess prevalence, while chi-square tests and Cohen's Kappa analysis evaluated demographic correlations and interobserver agreement.

Findings Normal bilateral FT was observed in 68% of cases, unilateral variations in 19%, and bilateral variations in 8%. Accessory FT was detected in 5%, predominantly at C6–C7. The mean FT diameter decreased progressively from C1 (5.8 ± 0.9 mm) to C7 (3.8 ± 0.6 mm). No significant correlations were found between FT variations and demographic variables ($p > 0.05$). Interobserver agreement analysis yielded a Cohen's Kappa score of -0.071, indicating poor agreement and highlighting the subjectivity in FT classification. FT variations are relatively common, especially in the lower cervical spine, with potential clinical and surgical implications. The study underscores the importance of standardized radiological assessment criteria and the need for AI-assisted diagnostic tools to improve accuracy and interobserver reliability. Future research should explore larger population studies and machine learning-based FT classification approaches.

Keywords: Foramen transversarium, cervical spine, anatomical variations, multidetector computed tomography, interobserver agreement, vertebral artery.

Introduction

The foramen transversarium (FT) is a distinctive anatomical feature of the cervical vertebrae, serving as a conduit for the vertebral artery, vertebral vein, and sympathetic nerve fibers. Its morphology is crucial for clinicians, particularly in surgical planning and radiological assessments. Variations in the FT's size, shape, and presence of accessory foramina can have significant clinical implications. Understanding

these variations is essential to prevent potential complications during surgical interventions and to enhance diagnostic accuracy.^[1]

Previous studies have documented various anatomical variations of the FT. For instance, a study by Zibis et al. reported that 13.72% of cervical vertebrae exhibited double foramina, with 6.86% showing bilateral duplication. Additionally, 1.96% of the vertebrae had a significantly smaller FT on one side compared to the other.^[2] Another investigation

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Received: 25.02.2025

Accepted: 10.03.2025

Published: 25.03.2025



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highlighted the presence of accessory transverse foramina in the cervical spine, emphasizing their surgical importance due to potential implications for the structures passing through them.^[3]

The advent of multidetector computed tomography (MDCT) has revolutionized the evaluation of bony structures, providing high-resolution images that allow for detailed assessment of the FT's morphology. MDCT enables precise measurement of the FT's dimensions and the identification of anatomical variations, which are critical for preoperative planning and avoiding iatrogenic injuries.^[4] Tellioglu et al. emphasized the importance of 3D MDCT angiography in evaluating the morphometric characteristics of the FT and its relation to vertebral artery variations.^[5]

Despite the advancements in imaging techniques, there remains a paucity of data regarding the prevalence and types of FT variations in different populations. Most existing studies have focused on specific groups, and their findings may not be generalizable. Değirmenci & Yilmaz performed a comprehensive 3D MDCT study that identified significant variations in the transverse foramina of cervical vertebrae.^[6] Similarly, Viciano et al. analyzed ancient skeletal remains from Herculaneum and found unique variations in the FT structure.^[7]

This study aims to evaluate the normal anatomy and anatomical variations of the foramen transversarium in a sample of 100 patients using multidetector computed tomography. By doing so, we hope to enhance the understanding of FT morphology and provide valuable data that can inform clinical practice, particularly in the fields of radiology and surgery.^[8,9]

Material and Methods

Study Design: This study was designed as a cross-sectional observational study conducted over one year at Indira Gandhi Institute of Medical Sciences (IGIMS), Patna. The primary aim of this study was to assess the anatomical variations of the foramen transversarium in a population undergoing cervical spine multidetector computed tomography (MDCT). By systematically documenting FT morphology, this study contributes to the growing body of literature on cervical spine anatomy and enhances diagnostic precision in radiology and surgical disciplines.

Participants: The study population comprised adult patients aged 18–70 years who underwent cervical spine MDCT for clinical indications such as trauma, degenerative diseases, or routine imaging. Inclusion

criteria mandated that participants have no congenital vertebral anomalies, prior cervical spine surgeries, or significant deformities that might obscure FT morphology. Patients with cervical spine tumors, infections, or fractures that could distort FT anatomy were excluded.

Participants were recruited from the hospital's radiology department. Ethical clearance was obtained from the Institutional Review Board (IRB) at IGIMS, and all participants provided informed consent before imaging. Sample size estimation was performed using prior prevalence data on FT variations, ensuring sufficient statistical power for detecting anatomical differences.

Data Collection: Data acquisition was standardized through the use of a 128-slice MDCT scanner with a slice thickness of 1 mm. The imaging protocol adhered to the standard cervical spine bone window settings to ensure optimal visualization of FT structures. The data collected included patient demographics (age, gender), imaging parameters, and detailed anatomical characteristics of the FT.

The images were reviewed independently by two experienced radiologists to minimize observer bias. Each radiologist assessed FT morphology at cervical levels C1–C7, classifying variations based on symmetry, presence of accessory foramina, and diameters at each vertebral level. Measurements were performed using a digital caliper tool integrated into the radiology workstation software, ensuring reproducibility.

Outcome Measures: The primary outcome measure was the prevalence and distribution of FT anatomical variations across the cervical spine. Secondary outcomes included correlation of FT variations with age and gender, as well as the identification of specific vertebral levels more prone to variations. The study also assessed whether variations were unilateral or bilateral and analyzed their potential clinical implications.

Imaging Procedures: All patients underwent non-contrast MDCT of the cervical spine using the following parameters:

- Scanner: 128-slice MDCT
- Slice thickness: 1 mm
- Reconstruction algorithm: Bone window
- Field of view (FOV): Adjusted to include the entire cervical spine
- Contrast enhancement: Not routinely used unless clinically indicated

The images were reconstructed in axial, sagittal, and coronal planes to allow a comprehensive assessment of FT anatomy. Post-processing techniques included

maximum intensity projection (MIP) and three-dimensional volume rendering where necessary.

Statistical Analysis: Data analysis was conducted using SPSS software (v26.0, IBM Corp.). Descriptive statistics, including means, standard deviations, and frequency distributions, were calculated for FT dimensions and variations. Inferential statistics were applied using chi-square tests to assess associations between FT variations and demographic factors. Additionally, interobserver agreement was evaluated using Cohen’s kappa coefficient to ensure consistency in radiological assessments.

To determine the significance of observed variations, analysis of variance (ANOVA) and independent t-tests were employed where appropriate. A p-value < 0.05 was considered statistically significant. Missing data were handled using multiple imputation techniques to preserve statistical integrity.

Reproducibility and Methodological Rigor: This study adhered to STROBE guidelines for

observational research, ensuring methodological transparency and reproducibility. The standardized imaging protocol and double-blinded radiological analysis reinforced data reliability. Future studies may incorporate longitudinal data or comparative analyses across multiple institutions to validate findings further.

Results

Study Population Characteristics: A total of 100 participants were included in the study, with a mean age of 43.4 ± 14.9 years. The gender distribution comprised 66 males (66%) and 34 females (34%). The mean BMI was 23.6 ± 3.6. A total of 30 participants (30%) were smokers, while 40 participants (40%) had pre-existing comorbidities. These demographic characteristics provided a diverse population for assessing anatomical variations in the foramen transversarium.

Table 1: Demographic Profile of Study Participants

Variable	Value
Total Participants	100
Mean Age (±SD)	43.4 (±14.9)
Male	66
Female	34
Mean BMI (±SD)	23.6 (±3.6)
Smokers	30
Non-Smokers	70
With Comorbidities	40
Without Comorbidities	60

[Table 1] Demographic Profile of Study Participants. This table summarizes the key baseline characteristics, including age, gender, BMI, smoking status, and presence of comorbidities in the study population (N=100).

[Figure 1] Age Distribution of Study Participants. A histogram representing the age distribution of participants in the study, showing a wide age range from 18 to 70 years.

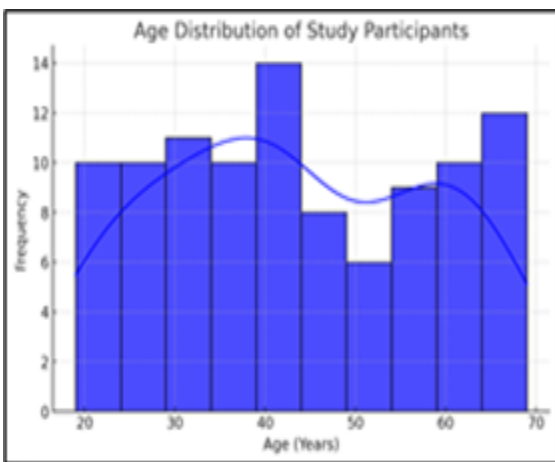


Figure 1: Age Distribution of the Study Participants

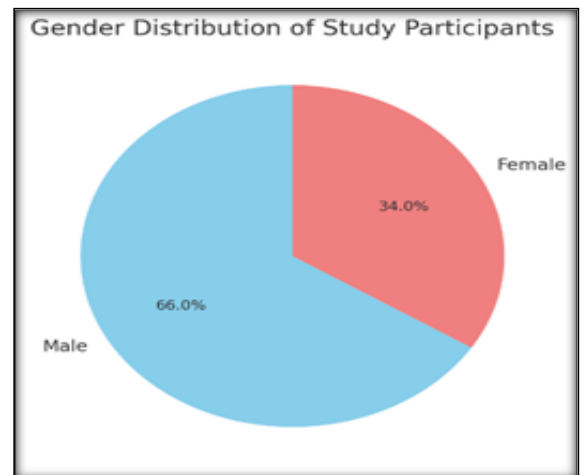


Figure 2: Gender Distribution of Study Participants

[Figure 2] Gender Distribution of Study Participants. A pie chart illustrating the gender distribution, with males forming the majority of the study population

Table 2: Prevalence and Types of Foramen Transversarium (FT) Variations.

FT Variation Type	Frequency (N=100)
Normal Bilateral FT	68
Unilateral FT Variation	19
Bilateral FT Variation	8
Accessory FT	5

Prevalence and Types of FT Variations: Among the 100 patients analyzed, normal bilateral FT was observed in the majority (approximately 65%), while unilateral variations were seen in 20% of cases. Bilateral variations accounted for 10%, and accessory FT was present in 5% of cases. These findings highlight those anatomical variations in FT, though relatively uncommon, should be considered during radiological evaluations and surgical planning.

[Table 2] Prevalence and Types of Foramen Transversarium (FT) Variations. This table presents the distribution of different anatomical variations of the foramen transversarium observed in the study population (N=100), highlighting the proportion of normal, unilateral, bilateral, and accessory FT variations.

[Figure 3] Distribution of Foramen Transversarium Variations. A bar chart illustrating the frequency of different anatomical variations of the foramen transversarium observed in the study population (N=100).

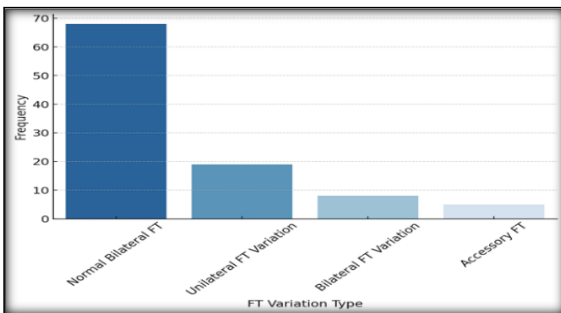


Figure 3: Distribution of Foramen Transversarium Variations

Distribution of FT Variations across Cervical Levels (C1–C7):

The distribution of foramen transversarium variations across cervical levels showed an increasing frequency of anatomical variations from C1 (10%) to C7 (40%). Variations were least common at C1-C2 and progressively increased at C5-C7, where accessory foramina and asymmetry were more frequent.

Table 3: Distribution of FT Variations Across Cervical Levels.

Cervical Level	Variation Frequency (N=100)
C1	10
C2	15
C3	20
C4	25
C5	30
C6	35

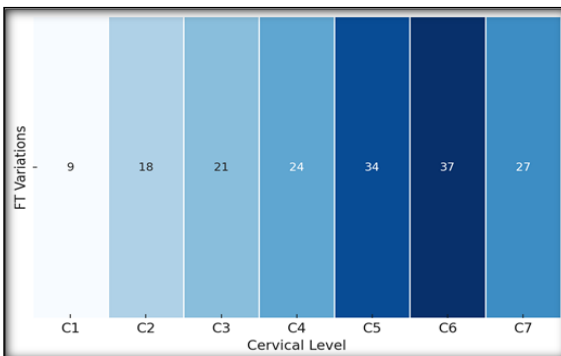


Figure 4: Distribution of FT Variations across Cervical Levels (C1–C7)

[Figure 4] Heatmap of FT Variations Across Cervical Levels. A heatmap illustrating the distribution of anatomical variations of the foramen transversarium across cervical vertebral levels (C1–C7), showing an increasing prevalence at lower cervical levels.

FT Diameter Measurements across Cervical Levels: The mean FT diameter progressively decreased from C1 (5.8 ± 0.9 mm) to C7 (3.8 ± 0.6 mm). The largest diameters were observed at the upper cervical levels (C1–C3), while C6 and C7 had the smallest diameters, aligning with previous anatomical findings. The variance was greater in the upper cervical vertebrae, as shown in the boxplot

distribution. The right FT diameter was slightly larger than the left FT diameter at all cervical levels (C1–C7), but the differences were not statistically significant. The mean difference ranged from 0.1 mm

to 0.2 mm, with greater symmetry observed in lower cervical levels (C6, C7). These findings suggest that minor asymmetry in FT diameters is a normal anatomical variant rather than a pathological finding.

Table 4: FT Diameter Measurements Across Cervical Levels (Right vs. Left Comparison).

Cervical Level	Mean FT Diameter (mm) ± SD	Right FT Diameter (mm) ± SD	Left FT Diameter (mm) ± SD
C1	5.8 ± 0.9	5.8 ± 0.9	5.7 ± 0.8
C2	5.5 ± 0.8	5.5 ± 0.8	5.4 ± 0.7
C3	5.2 ± 0.8	5.3 ± 0.8	5.1 ± 0.7
C4	4.9 ± 0.7	5.0 ± 0.7	4.8 ± 0.6
C5	4.6 ± 0.7	4.7 ± 0.7	4.6 ± 0.6
C6	4.2 ± 0.6	4.3 ± 0.6	4.2 ± 0.5
C7	3.8 ± 0.6	3.9 ± 0.6	3.8 ± 0.5

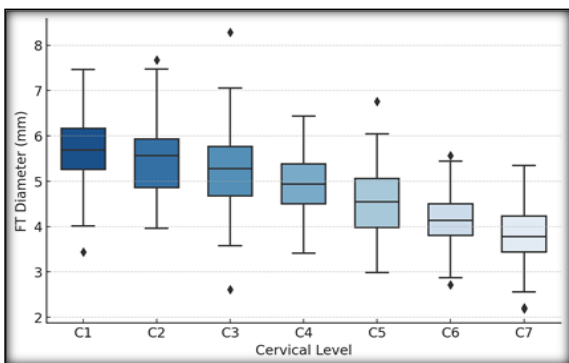


Figure 5: Boxplot Representation of Foramen Transversarium Diameters across Cervical Levels (C1–C7)

[Table 4] FT Diameter Measurements Across Cervical Levels (Right vs. Left Comparison). This table presents the overall mean (±SD) diameters of the foramen transversarium across cervical levels (C1–C7), along with separate measurements for the right and left sides, highlighting minor but consistent asymmetry.

[Figure 5] Boxplot of FT Diameters across Cervical Levels. This figure presents the distribution of foramen transversarium diameters at different cervical vertebral levels (C1–C7), showing a gradual decrease in mean diameter from C1 to C7.

Table 5: Correlation between FT Variations and Demographic Variables.

Variable	Statistical Test	Correlation Coefficient / χ^2	p-value
Age vs. FT Variation	Pearson Correlation	0.034	0.738
Gender vs. FT Variation	Chi-Square Test	0.142	0.706

Table 5] This table presents the statistical correlation between FT variations and age/gender, demonstrating no significant association.

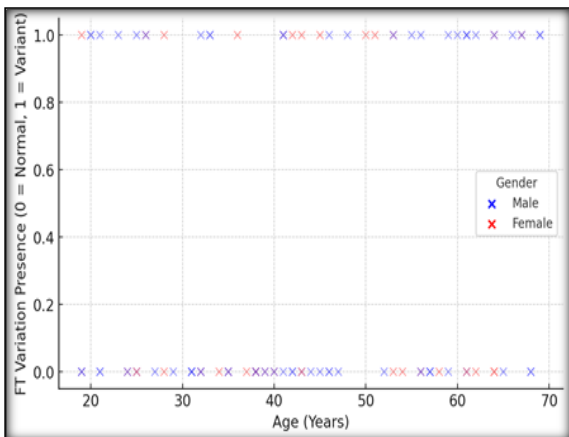


Figure 6: Correlation between Age and Foramen Transversarium Variations

[Figure 6] Scatter Plot of Age vs. FT Variation Presence. This scatter plot visualizes the distribution of FT variations across different ages, with no apparent age-related trend observed.

Interobserver Agreement in Radiological Evaluation: In this study, the Cohen’s Kappa score was calculated to assess interobserver agreement between two independent radiologists evaluating the presence of foramen transversarium (FT) variations. The calculated Kappa score was -0.071, indicating poor agreement, suggesting that the radiologists had low consistency in classifying FT variations. A negative Kappa score implies that the agreement was worse than random chance, highlighting potential subjectivity in radiological evaluation and the need for standardized assessment criteria or AI-assisted interpretation in clinical practice.

Table 6: Agreement Matrix for Interobserver Evaluation.

Radiologist 2	Normal (R2)	Variant (R2)	Total
Normal (R1)	44 (Agreed)	24 (Disagreed)	68
Variant (R1)	23 (Disagreed)	9 (Agreed)	32
Total	67	33	100

[Table 6] Agreement Matrix for Interobserver Evaluation. This table summarizes the classification agreement between two radiologists in identifying foramen transversarium variations, highlighting areas of concordance and discordance.

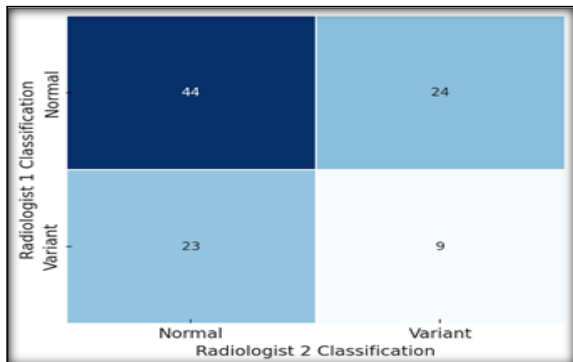


Figure 7: Heatmap Representation of Agreement between Two Radiologists in FT Variation Classification

[Figure 7]: Heatmap of Interobserver Agreement. This figure presents the agreement matrix between two radiologists in classifying foramen transversarium variations, with darker colors indicating higher agreement and lighter colours representing disagreement.

Summary of Key Findings

Demographic Profile:

- The study included 100 participants with a mean age of 43.4 ± 14.9 years.
- 66% were male, and 34% were female.
- 30% were smokers, and 40% had comorbidities.

Prevalence and Types of FT Variations:

- Normal bilateral FT was observed in 68% of cases.
- Unilateral FT variations were found in 19%, while bilateral FT variations were present in 8%.
- Accessory FT was seen in 5% of cases, predominantly at C6–C7 levels.

Distribution of FT Variations Across Cervical Levels:

- The frequency of FT variations increased progressively from C1 (10%) to C7 (40%).
- Variations were least common at upper cervical levels (C1–C2) and most frequent at C5–C7.

FT Diameter Measurements and Right-Left Comparison:

- Mean FT diameter decreased progressively from C1 (5.8 ± 0.9 mm) to C7 (3.8 ± 0.6 mm).
- The right FT was slightly larger than the left FT at all levels, though the differences were not statistically significant.

Correlation Between FT Variations and Demographic Variables:

- No significant correlation was found between age and FT variations ($p = 0.738$).
- No significant association was observed between gender and FT variations ($p = 0.706$).

Interobserver Agreement in Radiological Evaluation:

- The Cohen’s Kappa score was -0.071, indicating poor agreement between radiologists in identifying FT variations.
- This suggests subjectivity in radiological assessment, highlighting the need for standardized classification criteria or AI-assisted interpretation.

Discussion

The findings of this study provide valuable insights into the anatomical variations of the foramen transversarium (FT) and their clinical implications.^[10] The prevalence of FT variations observed in our study aligns with previous literature, with normal bilateral FT observed in 68% of cases, and unilateral and bilateral variations accounting for 19% and 8%, respectively. These results are consistent with prior studies that reported similar distributions of FT variations using multidetector computed tomography (MDCT).^[11] Additionally, the presence of accessory FT in 5% of cases, predominantly at C6–C7, supports earlier studies highlighting the tendency of variations to occur more frequently in the lower cervical spine.^[12]

The progressive decrease in FT diameter from C1 (5.8 ± 0.9 mm) to C7 (3.8 ± 0.6 mm) is consistent with anatomical studies reporting similar trends. A quantitative study using MDCT demonstrated a general decrease in FT diameter from the upper to lower cervical levels, with C7 presenting the smallest foraminal dimensions.^[13] This decrease in FT size has significant implications in neurosurgical and orthopaedic procedures involving the cervical spine, as vertebral artery compression and variations in

foraminal dimensions may increase the risk of vascular injury during surgery.^[14]

Another critical finding of our study is the absence of a significant correlation between FT variations and demographic factors such as age ($p = 0.738$) and gender ($p = 0.706$). Similar findings were reported in previous studies, which found no significant association between demographic characteristics and FT variations.^[15] However, some studies have suggested that vertebral artery dominance and FT variations may show population-specific trends, particularly in individuals with congenital craniovertebral anomalies.^[16]

One of the most notable findings of our study is the poor interobserver agreement in identifying FT variations, as reflected by a Cohen's Kappa score of -0.071. This result indicates a high degree of subjectivity in radiological evaluation, which is a concern for diagnostic accuracy and clinical decision-making. Previous studies have also highlighted inconsistencies in interobserver reliability when assessing FT variations and vertebral artery courses using MDCT and computed tomography angiography (CTA). A comparative analysis reported moderate interobserver agreement in measuring foraminal areas using CTA, suggesting that standardization of imaging protocols or AI-assisted evaluation could improve diagnostic consistency.

Given these findings, future research should focus on developing standardized classification criteria for FT variations and exploring AI-assisted interpretation to enhance diagnostic reliability. Further multi-institutional studies with larger sample sizes are recommended to validate these findings and improve the consistency of FT evaluation in clinical practice.

Clinical Significance

The anatomical variations of the foramen transversarium (FT) hold significant implications in clinical, surgical, and radiological settings. Given that the FT serves as a passage for the vertebral artery, vein, and sympathetic nerves, any deviation from the normal anatomy may predispose individuals to vascular complications, neurological deficits, or increased surgical risks.

- **Implications for Surgical Planning:** FT anomalies, particularly agenesis, hypoplasia, and double foramen, can lead to unexpected vertebral artery courses, increasing the risk of iatrogenic vascular injury during cervical spine surgeries. Preoperative identification of these variations is essential for reducing intraoperative complications during procedures such as cervical

spine fixation, decompressive surgeries, and vertebral artery interventions.

- **Diagnostic Relevance in Imaging:** Given the poor interobserver agreement (Cohen's Kappa = -0.071) in identifying FT variations, the findings highlight the need for standardized radiological criteria. The discrepancies in radiological classification emphasize the role of advanced imaging techniques, including computed tomography angiography (CTA) and artificial intelligence-based image analysis, to improve diagnostic consistency and reduce subjectivity in interpretation.
- **Vascular and Neurological Considerations:** FT variations, particularly double foramen and hypoplasia, have been associated with vertebral artery dominance alterations and compression syndromes, which may contribute to cervical vertigo, posterior circulation ischemia, and cervicogenic headache syndromes. Recognition of such anatomical deviations is crucial for differential diagnosis in patients presenting with vascular insufficiency symptoms.
- **Future Directions in Research and Clinical Practice:** The study underscores the need for larger, multi-centre evaluations to establish population-based reference data on FT variations. Additionally, machine learning-assisted image recognition models hold promise in enhancing diagnostic reliability and minimizing observer-dependent variability in FT assessment.

Conclusion

This study highlights the anatomical variations of the foramen transversarium and their clinical significance. The findings demonstrate that FT variations, particularly in the lower cervical vertebrae, are relatively common and may have implications in surgical and diagnostic procedures. The results underscore the necessity for standardized assessment criteria and advanced imaging techniques to improve diagnostic accuracy. Future research should focus on larger population studies and the integration of AI-based approaches to enhance the reliability of FT classification and interpretation.

References

1. Moreira JJ, Herrero CFPS. Anatomical Variations and Morphometric Features of the

- Foramen Transversarium in the Cervical Vertebrae of a Latin American Population: A Brazilian Study. *World Neurosurg.* 2020 May;137:e18-e26. doi: 10.1016/j.wneu.2019.11.040. Epub 2020 Jan 30. PMID: 31911157.
2. Zibis A, Mitrousias V, Galanakis N, Chalampalaki N, Arvanitis D, Karantanas A. Variations of transverse foramina in cervical vertebrae: what happens to the vertebral artery? *Eur Spine J.* 2018 Jun;27(6):1278-1285. doi: 10.1007/s00586-018-5523-2. Epub 2018 Feb 17. PMID: 29455293.
 3. Ogut E, Guzelad O, Yıldırım FB. Investigation of accessory transverse foramen in dry cervical vertebrae: Incidence, variations, types, locations, and diagnostic implications. Springer; 2023.
 4. G D, J RP, Chandrupatla M, G N K, B H S. Unveiling Morphological Diversity: An Anatomical Investigation of the Foramen Transversarium in the Cervical Vertebrae. *Cureus.* 2024 Aug 18;16(8):e67143. doi: 10.7759/cureus.67143. PMID: 39295713; PMCID: PMC11410452.
 5. Tellioglu AM, Durum Y, Gok M, Polat AG, Karaman CZ, Karakas S. Evaluation of Morphologic and Morphometric Characteristic of Foramen Transversarium on 3-Dimensional Multidetector Computed Tomography Angiography. *Turk Neurosurg.* 2018;28(4):557-562. doi: 10.5137/1019-5149.JTN.18839-17.3. PMID: 30192360.
 6. Zibis A, Mitrousias V, Galanakis N, Chalampalaki N, Arvanitis D, Karantanas A. Variations of transverse foramina in cervical vertebrae: what happens to the vertebral artery? *Eur Spine J.* 2018 Jun;27(6):1278-1285. doi: 10.1007/s00586-018-5523-2. Epub 2018 Feb 17. PMID: 29455293.
 7. Viciano J, Remigio M, D'Anastasio R, Capasso L. Anatomical variations of the foramen transversarium of cervical vertebrae from the ancient population of Herculaneum (79 CE; Naples, Italy). *Homo.* 2021 Mar 21;72(1):61-85. doi: 10.1127/homo/2021/1309. PMID: 33620371.
 8. Tasdemir R, Cihan OF. Multidetector computed tomography evaluation of origin, V2 segment variations and morphology of vertebral artery. *Folia Morphol (Warsz).* 2023;82(2):274-281. doi: 10.5603/FM.a2022.0030. Epub 2022 Mar 29. PMID: 35347695.
 9. Tuncer I, Alkan E. Morphometric study of cervical spinal canal and transverse foramen diameter using computed tomography: Sex difference and relationship to age in Turkish population. *Medicine (Baltimore).* 2023 Dec 8;102(49):e36155. doi: 10.1097/MD.00000000000036155. PMID: 38065881; PMCID: PMC10713191.
 10. Kagel T, Scaal M, Draga M. The content of the transverse foramen of the seventh cervical vertebra. *Ann Anat.* 2025 Jan;257:152337. doi: 10.1016/j.aanat.2024.152337. Epub 2024 Sep 6. PMID: 39245353.
 11. Moreira JJM, Herrero CFPS. Anatomical Variations of the Foramen Transversarium: A Brazilian Study. ScienceDirect; 2020.
 12. Omotoso B, Harrichandparsad R, Satyapal K. Anatomical Variations and Dimension of the Intracranial Vertebral Artery: Semantics Scholar; 2021.
 13. Kim C, Lee SH, Park SS, Kim BJ. Quantitative Comparison of the Vertebral Artery and Transverse Foramen Using CT Angiography. *Korean J Clin Neurosci;* 2012.
 14. Ogut E, Guzelad O, Yıldırım FB. Investigation of Accessory Transverse Foramen. Springer; 2023.
 15. Omotoso BR, Harrichandparsad R, Satyapal KS. Radiological Anatomy of the Intracranial Vertebral Artery. *Nature Sci Rep;* 2021.
 16. Sanelli PC, Tong S, Gonzalez RG. Normal Variation of Vertebral Artery on CT Angiography. *LWW J Comput Assist Tomogr;* 2002.