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Study of the Relationship between the Transverse Foramina of The Cervical Vertebrae and the Corresponding Vertebral Arteries in Human Vertebral Column by Using Contrast Computed Tomography

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ABSTRACT
Background: The vertebral arteries (VA) and internal carotid arteries play a crucial role in cerebral blood flow, with cervical vertebrae contributing significantly to vascular supply through their transverse foramina.
Objective: This study examined the relationship between transverse foramina cross-sectional areas (C1-C6) and corresponding VA dimensions to enhance understanding of vascular variations impacting cerebral perfusion.
Subjects and methods: This prospective study included 30 subjects (age 25-55) who underwent contrast-enhanced CT angiography for non-neurological symptoms. Measurements of right and left transverse foramina (RF and LF) and VA (RV and LV) were recorded. Statistical analysis was conducted using paired t-tests and Spearman's correlation via SPSS version 16.0.
Results: Mean cross-sectional areas of RF and LF were largest at C1 and C2, decreasing from C3 to C6. Significant side-to-side variance was noted at C1 ($p < 0.05$) but not at other levels. Positive correlations were observed between transverse foramen and vertebral artery areas (r^2 for right side = 0.86, $p < 0.001$; left side = 0.53, $p < 0.001$), indicating an association between foramina and artery size.
Conclusion: The transverse foramina dimensions correlated strongly with vertebral artery size, which may aid in diagnostic and surgical planning in cervical spine procedures. CT angiography is recommended for detailed assessment of vertebral artery anomalies.
Keywords: CT angiography, Cervical vertebrae, Vertebral arteries, Transverse foramina.

INTRODUCTION
The vertebral arteries (VA), along with internal carotid arteries, are essential for maintaining adequate blood flow to central nervous system [1]. Contributing approximately 28% of blood supply to brain's posterior regions, brainstem, upper spinal cord, and cerebellum, VA hold a substantial role in cerebrovascular health [2, 3]. As they ascend through transverse foramina of cervical vertebrae, these arteries deliver critical circulation to brain. Typically, their diameter ranges between 3-5 mm, with stenosis frequently occurring at ostium. In paleontological studies, transverse foramina dimensions have served as a reliable proxy for estimating vertebral artery size [4, 5].

The VA usually arise from proximal subclavian artery, traveling from C6 to C1 via transverse foramina before entering foramen magnum and merging with opposite side to form basilar artery [6]. Occasionally, they originate from brachiocephalic arteries, more commonly on right, or aortic arch on left, leading to an alternative entry at C5 instead of usual C6 [7].

The VA is anatomically segmented into four parts (V1-V4): V1 extends from its origin to C6 entrance, V2 runs from C6 to C1 within transverse foramina, V3 spans from C1 to dura, and V4 is intracranial section [2].

Proper cervical vertebrae development is crucial for vertebral artery formation, with size reduction of arteries potentially arising from congenital or acquired factors [8]. Unique shapes of atypical C1 and C2 vertebrae are particularly relevant in clinical settings, as they pose a notable risk to vertebral artery during surgical procedures [9]. Atlas (C1) stands out structurally due to its ring-like form and absence of a vertebral body, marked by lateral masses through which vertebral artery exits and follows a groove lateral to spinal canal and posterior to lateral mass [10].

This study examined the relationship between transverse foramina cross-sectional areas (C1-C6) and corresponding VA dimensions to enhance understanding of vascular variations impacting cerebral perfusion.

SUBJECTS AND METHODS
Study design and patient population: This prospective study was done on 30 subjects aging from 25- 55 years (3:1, male: female) all from Sohag. Population were gathered from Radiology Unit at Sohag University Hospitals. In the period from February 2023 to August 2023, any patient who did neck and cerebral CT angiography to detect shakiness and headaches that not related to any pivotal neurologic shortages or to intracranial aneurysm was included.

Exclusion criteria: Subjects with vertebral column congenital deformities, pathologies or trauma.

Imaging analysis: A GE 128-slice CT scan of neck was performed on a patient in supine position, both pre-contrast and post-contrast, inside gantry at hospital. Examination started at skull base and extended to arch of aorta in a cranio-caudal direction, with section thickness ranging from 0.5 to 1 mm and a field of view of about 32 cm. Surface areas of transverse foramina

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(right and left) and VA (right and left) were measured (Figure 1 & 2).

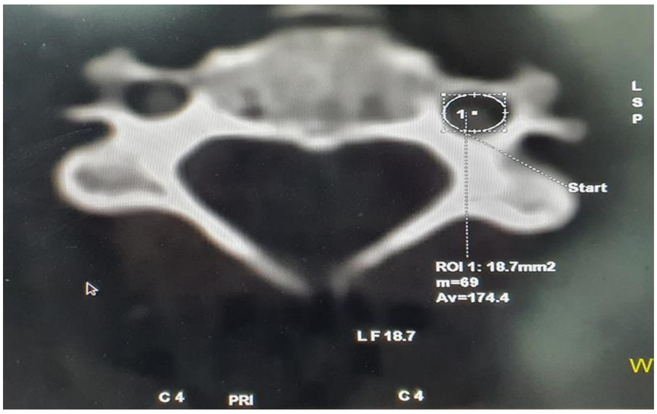

Figure (1): Dimensions of cross-sectional areas of foramen transversum of left 4th cervical vertebra.

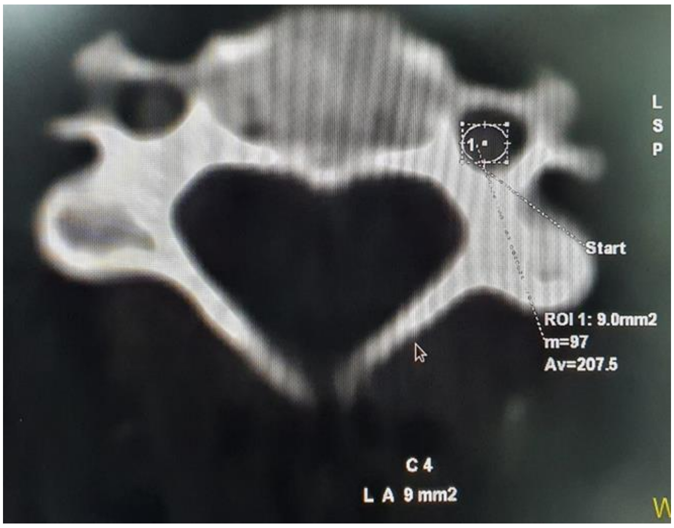

Figure (2): Dimensions of cross-sectional areas of arteria vertebralis pass through left 4th cervical vertebra.

Data collection:

We measured cross-sectional areas of right (RF) and left (LF) foramina transversaria, as well as right (RV) and left (LV) VA, in comparable people from C1 to C6. Optimal plane for each foramen was determined by placing landmarks along foraminal opening and using arterial post-contrast phase to quantify (RV and LV) surface areas (mm^2) by semi-automated methods, while pre-contrast phase was used to assess surface areas of RF and LF.

Ethical approvals: The study was done after being accepted by Research Ethics Committee, Sohag University (IRB.Soh-Med-23-09-20PD). All patients provided written informed consents prior to their enrolment. Consent form explicitly outlined their agreement to participate in study and for publication of data, ensuring protection of their confidentiality and privacy. This work has been carried out in accordance with Code of Ethics of World Medical Association (Declaration of Helsinki) for studies involving humans.

Statistical measures:

All statistical evaluations were conducted using SPSS version 26 (IBM, Armonk, New York, United States). Paired t-tests were used to determine side-to-side differences in sizes of TF and VA. Pearson's correlation analysis was used to examine linear connection between average areas of TF and VA. Average areas of TF and VA were estimated by summing computed areas at various levels from C1 to C6 and dividing by 6.

RESULT

Table (1) and figure (3) denoted dimensions of right foramina transversaria (RF) and left foramina transversaria (LF) cross-sectional areas at level of c1, c2, c3, c4, c5 and c6. Cross-sectional areas mean of foramina transversarium RF and LF were larger in c1 in addition to c2 in comparison with mean of cross-sectional area of c3 up to c6 cervical vertebrae.

There was significant variance between RF and LF at level of c1 ($p \leq 0.05$) while no significant variance between RF & LF at residual of cervical vertebra level.

Also, cross-sectional area of right vertebral artery (RV) and left vertebral artery (LV), revealed significant variance between area of RV & LV during its passage in different level of cervical vertebra.

Spearman's correlation assessment was used to appraise relationship among average area of VA and transverse foramen at right and left side where there was positive correlation between RV and RF & LV and LF where (r^2 of right side = .86, $p<0.001$), (r^2 of left side = .53, $p<0.001$). Area of vertebral artery increases alongside increase in area of transverse foramen (figures 4 & 5).

Table (1): Cross-sectional areas of right (RF) and left (LF) transverse foramina and right (RV) and left (LV) vertebral arteries across different cervical vertebral levels

Vertebra	RF	LF	P value	RV	LV	P value
C1	21.2±2.4*	20.7±2.05*	.006=0.01	10.9±1.5NS	10.9±1.2NS	.747
C2	21.06±2.4NS	20.2±2.3**NS**	.077	10.8±1.4 NS	11.7±.3.5 NS	.113
C3	20.5±2.44NS	20±2.21NS	.062	11.1±3.15NS	11.03±2.8NS	.512
C4	20.5±2.1 NS	20.2±1.8 NS	.161	10.4 ±1.33 NS	10.5 ± 1.07 NS	.533
C5	20.5±2.3 NS	20.3±1.8 NS	.129	10.4 ± 1.35 NS	10.48 ± 1.1 NS	.556
C6	19.7±3.26NS	19.8±3.9NS	.919	11.27±3.57NS	11.62±4.5NS	.293

RF = Right Foramen Transversarium; LF = Left Foramen Transversarium; RV = Right Vertebral Artery; LV = Left Vertebral Artery; SD = Standard Deviation; NS = Non-Significant, *=Significant difference, values mentioned= mean + SD.

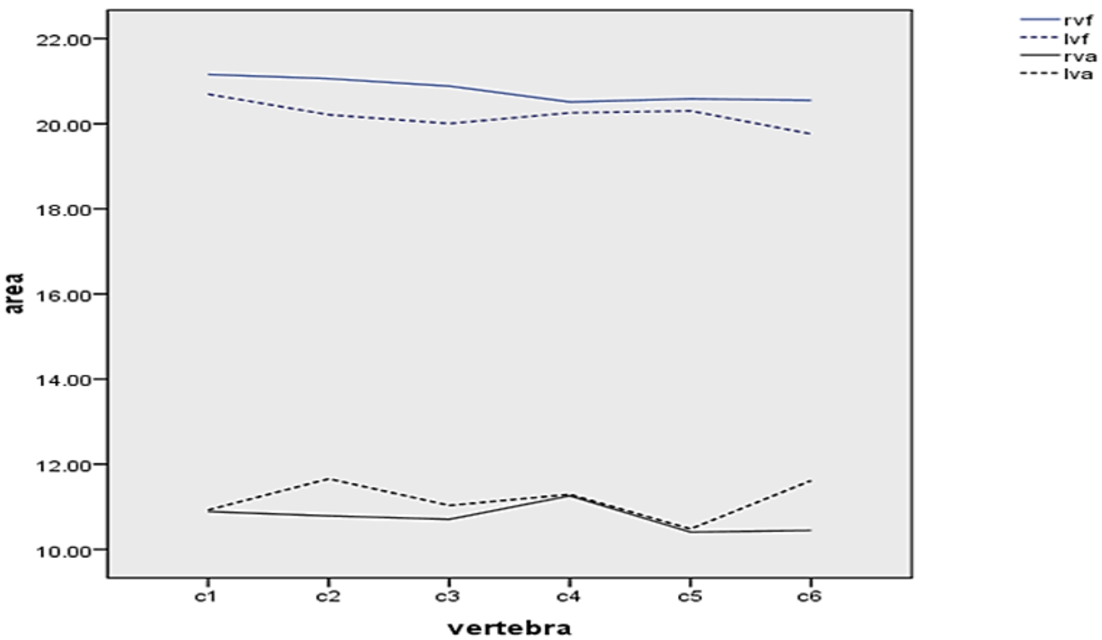

Figure (3): Mean of cross-sectional areas of right foramina (compact blue mark) and left foramina (spotted blue mark), right arteries (compact dark mark) and left vertebral artery (spotted dark mark) at different cervical vertebra.

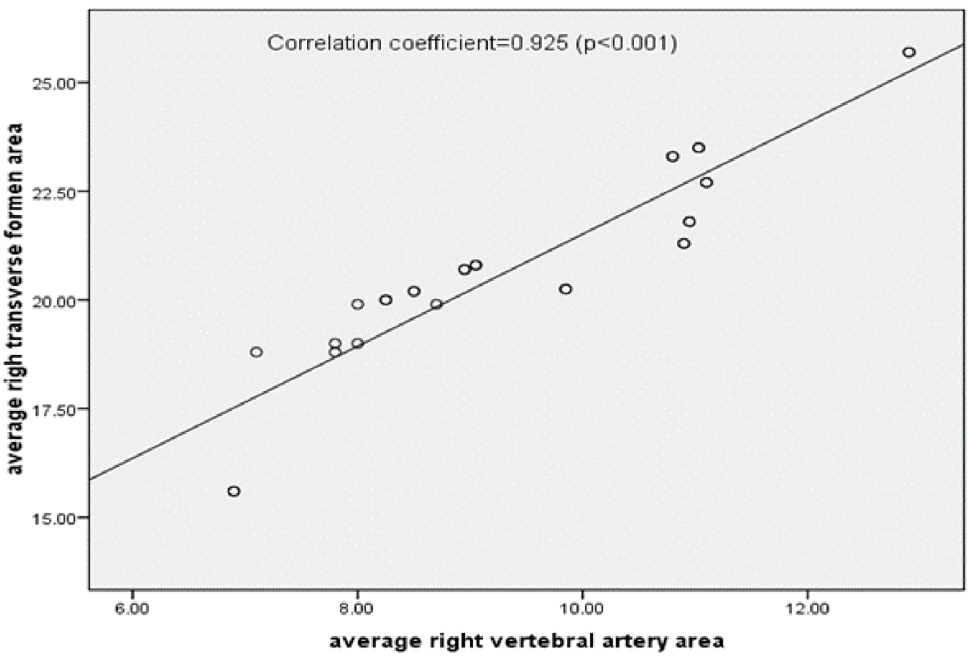

Figure (4): Scatter plot demonstrating correlations between areas of right vertebral artery and right transverse foramen, which showed a positive relationship among them.

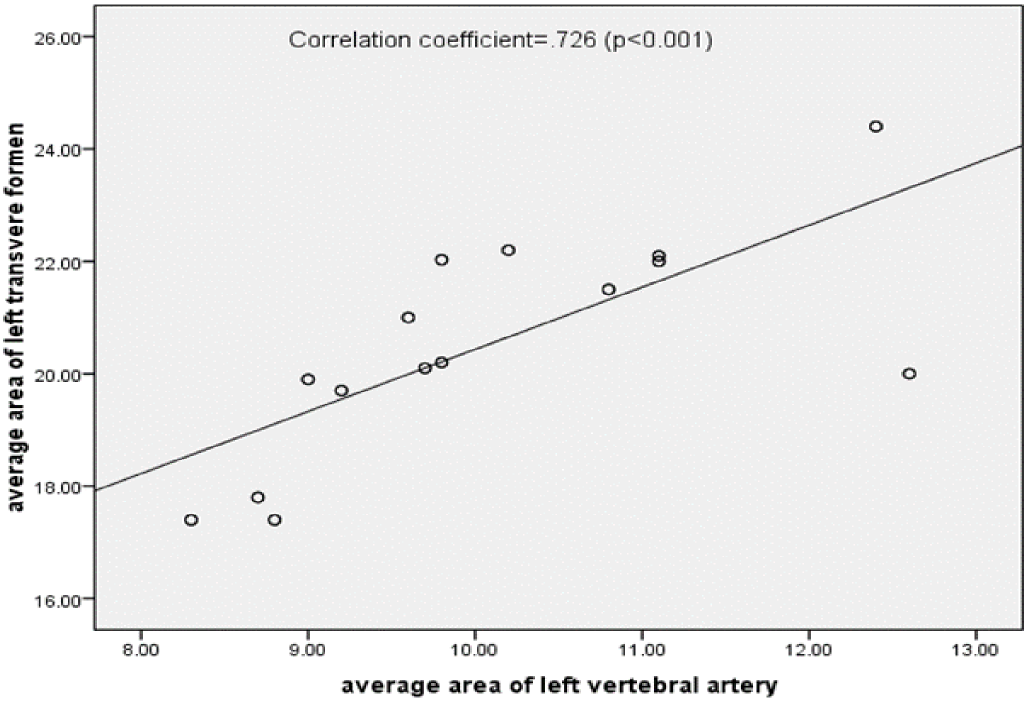

Figure (5): Scatter plot presenting relationship among areas of left vertebral artery and left transverse foramen, it implied a positive relationship between them.

DISCUSSION

Denis *et al*. [11] denoted that CT-angiography is an excellent manner in evaluating correlation coefficient relation between bony elements (TF) and VA for diagnosing various causes of VA narrowing.

Also, **Zaw *et al*.** [12] stated that any surgical procedure that includes cervical vertebrae variation in transverse foramen should be taken in consideration via knowing morphometric variances and laterality during cervical vertebrae radiological inquiries.

This study afforded initial data on association between transverse foramina and dimensions of arteries, which pass through their corresponding human cervical vertebrae. We found a positive relation between transverse foramen cross-sectional area and size of vertebral artery. Also, we didn't observe any asymmetry between right and left transverse foramen. In suggestion with **De Jager *et al*.** [13] who observed no significant disparity among right and left transverse foramina or arteries. **Alicioglu *et al*.** [14] and **Kültür *et al*.** [15] observed a positive link between dimensions of transverse foramina and arterial blood volume of C6 vertebra, as well as a reduction in diameters of bony structures or transverse foramen, which may result in a decrease in size of vertebral artery on corresponding side.

In conjunction with **Kotil and Kilincer** [16] and **Nalley and Grider-Potter** [17] demonstrated that CT scans of cervical vertebrae in 16 individuals measured cross-sectional areas of transverse foramina and their corresponding VA on both sides, ranging from C1 to C6. Measurements varied from 13.40 to 71.25 mm² for foramina and from 4.53 to 29.40 mm² for arteries, exhibiting a strong correlation, except at C1, which is attributed to biophysical function of atlas in neck movement. This is consistent with **Kim *et al*.** [8] who established that TF area exhibited a positive correlation with corresponding ipsilateral VA area, and a reduction in transverse foramen area relative to artery resulted in a reduced size of VA. **Hong *et al*.** [18] and **Vasudeva and Kumar** [19] proved that VA proportions was positively correlated with TF size and that CT angiography can be used in recognition of various vertebral artery pathologies, as large TF with a small VA, which represent good indication about massive hypoplasia or acquired stenosis of VA. In contrast, **De Jager *et al.*** [13], **Vasudeva and Kumar** [19] and **Tuncel *et al.*** (20) informed that area of vertebral artery was not declined in cases of double transverse foramen subjects, so smaller TF not affect area values of corresponding VA.

Sanchis-Gimeno *et al*. [21] and **Sanelli *et al*.** [22] indicated that significant normal variations exist in extent and localization of VA within transverse foramina among healthy young individuals, which should be considered when evaluating CT angiograms for vertebral artery issues. Also, **Shin *et al.*** [23] indicated that there were non-significant statistical variances in passage of vertebral artery between left and right sides, and most instances with C6 entrance of vertebral artery had a typical course on both sides.

LIMITATIONS

This study had several limitations. First, sample size of 30 subjects may limit generalizability of findings, as a larger cohort could provide more robust correlations. Additionally, study was conducted on a single population from Sohag, potentially limiting applicability of results to other demographics. Reliance on CT angiography, while effective for imaging vascular structures, may not capture subtle dynamic variations in vertebral artery dimensions influenced by posture or blood flow changes. Lastly, exclusion of patients with congenital vertebral anomalies and significant neurologic conditions may overlook important correlations relevant to these subgroups.

CONCLUSION

The alteration in the dimensions of vertebral artery was closely associated with size of transverse foramen, and angiography was most appropriate technique for assessing vertebral artery disorders related to abnormalities in cervical transverse foramen.

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