

Association Between Ponticuli and Morphometric Characteristics of the Foramen Transversarium in Human Atlas Vertebrae: A Retrospective Observational Study

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ABSTRACT

Introduction: The Ponticuli is a small bridge that connects the superior articulating facet and the vertebral artery groove. The vertebral artery passes through the Foramen Transversarium (FT) and then through the vertebral artery groove in the posterior arch of the atlas. If there is the presence of Ponticuli, the vertebral artery passes through the tunnel produced by the Ponticuli. The presence of Ponticuli is associated with neurological conditions. The hypothesis is since the vertebral artery passes through both the FT and the Ponticuli, any morphological alteration in one structure, the change may be reflected in other.

Aim: To find the prevalence of Ponticuli, morphology, and morphometry of the FT.

Materials and Methods: This retrospective observational study was conducted in the Department of Anatomy, PSG Institute of Medical Sciences and Research, Coimbatore, Tamil Nadu, India, over a six-month period from January 2016 to June 2016. on 200 Computed Tomography (CT) images of the atlas vertebra obtained from the Picture Archiving and Communication System (PACS), comprising 100 male and 100 female subjects.

The images were analysed in the Department of Anatomy over a period of six months with the guidance of radiologists. The prevalence and morphology of Ponticuli were assessed. The morphology of the FT was evaluated, and its morphometric parameters, including the anteroposterior and transverse diameters, were measured.

Results: Ponticuli were observed in 45 of the 200 atlas vertebrae, giving a prevalence of 22.5%. Among 100 males, Ponticuli were present in 21 (21%), whereas among 100 females they were present in 24 (24%). Among 200 vertebrae, the most common morphology of the FT on the right-side was Type 5, occurring in 132 (66%), and on the left side, Type 4 was predominant, occurring in 130 (65%). The anteroposterior diameter and the transverse diameter of the FT were 7.06 ± 1.11 mm and 5.80 ± 1.16 mm, respectively. Comparison of the anteroposterior diameter, transverse diameter, and morphological types of the FT with right- and left sided Ponticuli using Analysis of Variance (ANOVA) revealed no statistically significant differences (all $p > 0.05$).

Conclusion: Knowledge of the FT and Ponticuli is necessary for neurosurgeons and radiologists, and for spine procedures.

Keywords: Anteroposterior, Ponticuli lateralis, Ponticuli posterior

INTRODUCTION

The term Atlas is derived from Greek mythology. During the development of the atlas, ossification of the posterior atlanto-occipital membrane may result in the formation of an abnormal bony ridge extending from the posterior aspect of the superior articular facet to the posterolateral margin of the posterior arch. This bony bridge is termed Ponticulus Posticus (PP) and is also known as the arcuate foramen or Kimmerle's anomaly. It is believed to be influenced by neural crest cell development [1].

The transverse process contains the FT, through which the vertebral artery, vertebral vein, and sympathetic nerve plexus pass. Embryologically, the FT is formed by the posterior bar (forming the transverse process) and the costotransverse bar, which connects the costal element to the transverse process. These bars encircle the vertebral artery [2].

The third part (V3 segment) of the vertebral artery traverses the PP when present. Along with the artery, the suboccipital nerve and periarterial sympathetic plexus also pass through this region [3]. The presence of PP may lead to compression of these structures, producing symptoms such as muscle tension headache, migraine (with or without aura), tinnitus, vertigo, sensorineural hearing loss, diplopia, dysphagia, dysphonia, cervicobrachial syndrome, vertebral artery compression or dissection, and Barre-Lieou syndrome. However, many individuals with PP remain asymptomatic [4].

Atlantoaxial instability refers to excessive movement between the atlas and axis, presenting with symptoms such as headache, vertigo, balance disturbances, and blurred vision [5]. Surgical management often involves lateral mass screw fixation. During this procedure, the PP may be mistaken for the posterior arch of the atlas, leading to inadvertent injury to the vertebral artery and resulting in complications such as stroke, haemorrhage, thrombosis, or embolism [4,6]. Therefore, knowledge of this morphological variation is essential for neurosurgeons and radiologists [6].

Variations in the morphology of the FT lead to compression of the vertebral artery and exhibits anatomical variations; it remains vulnerable during surgical and interventional procedures. Alternative surgical approaches to the atlanto-occipital joint are increasingly preferred to minimise vascular risk [7].

Studies investigating the association between the presence of Ponticuli and the morphology and morphometry of the FT are scarce. To verify this hypothesis, the morphology and morphometry of the FT were compared with the presence or absence of ponticulus.

MATERIALS AND METHODS

This retrospective observational study was conducted in the Department of Anatomy, PSG Institute of Medical Sciences and Research, Coimbatore, Tamil Nadu, India, over a six-month period from January 2016 to June 2016 after obtaining approval from the Institutional Human Ethics Committee (IHEC No. 14/425).

Inclusion and Exclusion criteria: A total of 200 CT scans, comprising 100 males and 100 females aged 18-60 years, were included. Only scans with adequate image quality and normal atlas vertebrae were analysed. The CT scans with fractures, tumours, congenital anomalies of the craniovertebral junction, previous cervical spine surgery, degenerative changes were excluded from the study. The scans were classified and measured with the guidance of radiologists.

Study Procedure

Ponticuli were assessed using 3D reconstruction of brain and cervical spine CT images (5 mm slices). The cervical region was selected, and the atlas vertebra was isolated using Volume of Interest (VOI) punch mode. After removing surrounding tissues, the atlas was visualised in all directions to identify the presence of Ponticuli [Table/Fig-1].

Parameters observed: Ponticuli are defined as bony bridges extending from the dorsal or lateral aspect of the lateral mass to the vertebral artery groove on the posterior arch of the atlas (Akhtar MJ et al.,) [8].

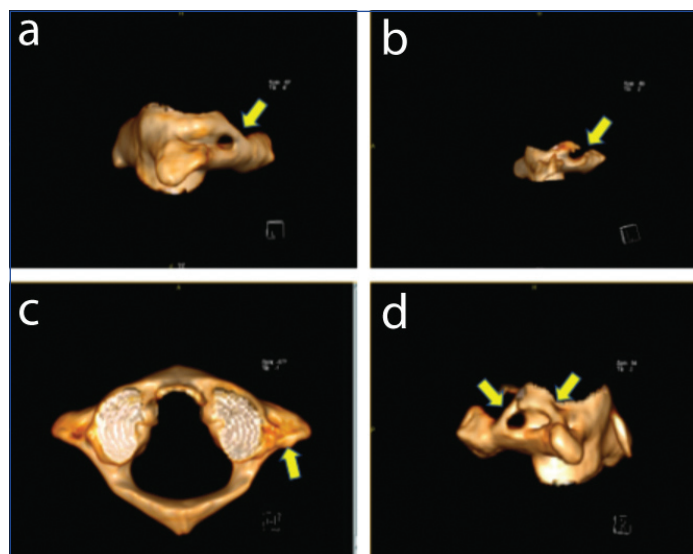
They were classified into three types:

Posterior Ponticuli: A bony bridge extending from the dorsal part of the superior articular facet to the posterior arch of the atlas.

Ponticuli lateralis: A bony bridge extending from the lateral part of the superior articular facet to the transverse process of the atlas.

Posterolateral Ponticuli: Presence of both Posterior Ponticuli and ponticuli lateralis on the same side.

Each Ponticuli were further categorised as partial and complete type [Table/Fig-1] [8,9].



[Table/Fig-1]: a) Complete posterior Ponticuli; b) Incomplete posterior Ponticuli; c) Complete Ponticuli lateralis; d) Complete posterolateral Ponticuli [8,9].

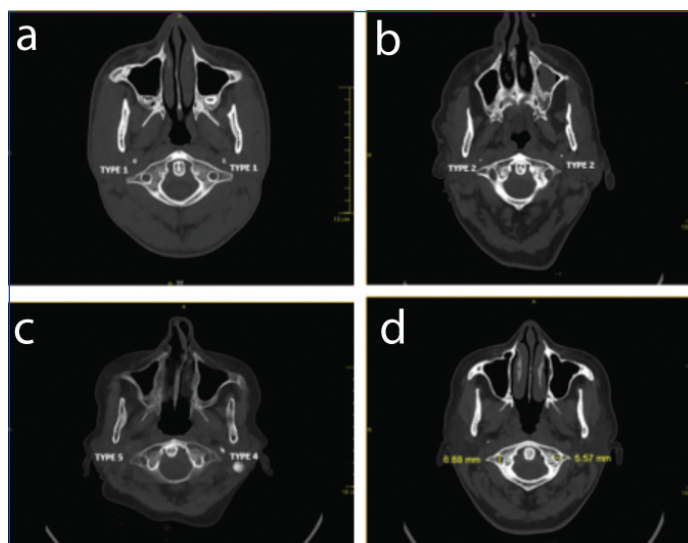
Foramen Transversarium (FT):

- Morphology:** The morphology of the FT was classified based on its shape and axis according to Taitz C et al., (1978) into five types [10]: Type 1 circular, type 2 oval in AP direction, type 3 oval in transverse direction, type 4 oval right to left axis, type 5 oval with left to right axis [Table/Fig-2].
- Morphometry:** A. Anteroposterior (AP) diameter/Length: Maximum distance in the anteroposterior plane. B. Transverse diameter/Width: Maximum distance in the mediolateral plane [Table/Fig-2] [10,11].

STATISTICAL ANALYSIS

Statistical analysis was performed using Statistical Package of Social Sciences (SPSS) version 27.0. The categorical variables were expressed as frequencies and percentages. The continuous variables were expressed as mean±standard deviation. One-way ANOVA

was used to assess the association between ponticulus and the morphology and morphometric parameters of the FT. Comparisons between males and females on the same side were conducted using an independent-samples t-test. Comparison of right versus left within each sex was also done using an independent-samples t-test. A Chi-square test was used to find the association between the types of FT and the presence or absence of Ponticuli. A p-value less than 0.05 was considered statistically significant.



[Table/Fig-2]: a) Type 1 Foramen Transversarium (FT); b) Type 2 Foramen Transversarium (FT); c) Right Type 4 Foramen Transversarium (FT), Left Type 5 Foramen Transversarium (FT); d) Anteroposterior diameter and Transverse diameter of Foramen Transversarium (FT).

RESULTS

Among the 200 images, type 5 is the highest frequency, followed by type 4. Among the right-sided FT, type 5 is the highest, and on the left side, FT type 4 is the highest [Table/Fig-3]. In male and female right-sided FT, there is no type 4. Among males and females, the right FT has type 5 as the highest frequency and type 4 on the left side [Table/Fig-4].

Type of morphology	Total (N=400)	Total right (n=200)	Total left (n=200)
Type 1	96 (24%)	45 (22.5%)	51 (25.5%)
Type 2	7 (1.75%)	3 (1.5%)	4 (2%)
Type 3	32 (8%)	20 (10%)	12 (6%)
Type 4	130 (32.5%)	0	130 (65%)
Type 5	135 (33.75%)	132 (66%)	3 (1.5%)

[Table/Fig-3]: The frequency distribution of morphology of Foramen Transversarium (FT) in CT images. Values presented as n (%).

Types	Male right (n=100)	Female right (n=100)	Male left (n=100)	Female left (n=100)
Type 1	19 (19%)	26 (26%)	25 (25%)	26 (26%)
Type 2	2 (2%)	1 (1%)	1 (1%)	3 (3%)
Type 3	10 (10%)	10 (10%)	6 (6%)	6 (6%)
Type 4	0	0	66 (66%)	64 (64%)
Type 5	69 (69%)	63 (63%)	2 (2%)	1 (1%)

[Table/Fig-4]: The frequency distribution of morphology among the gender and the right and left side of Foramen Transversarium FT. Values presented as n (%).

The mean AP diameter was 7.06 ± 1.11 mm and the transverse diameter was 5.80 ± 1.16 mm. Males showed larger dimensions (AP: 7.36 ± 1.11 mm; transverse: 6.16 ± 1.24 mm) compared to females (AP: 6.76 ± 1.03 mm; transverse: 5.45 ± 0.95 mm).

On side-wise analysis, the right FT measured 6.97 ± 1.19 mm (AP) and 5.75 ± 1.08 mm (transverse), while the left FT measured 7.15 ± 1.02 mm (AP) and 5.85 ± 1.25 mm (transverse).

A statistically significant sex difference was observed in the dimensions of the FT, with males exhibiting larger anteroposterior

diameters than females on both the right ($t=3.915$, $p=0.001$) and left sides ($t=4.091$, $p=0.001$). Comparison between the right and left sides revealed no significant difference in the transverse diameter ($t=-0.971$, $p=0.333$). Although a statistically significant difference was observed in the anteroposterior diameter between the right and left sides ($t=-2.142$, $p=0.033$), the magnitude of the difference was small [Table/Fig-5].

Parameters	Anteroposterior diameter	Transverse diameter
Right male	7.29±1.25 mm	6.04±1.13 mm
Right female	6.66±1.04 mm	5.48±0.95 mm
Left male	7.43±0.94 mm	6.28±1.32 mm
Left female	6.86±1.02 mm	5.42±0.95 mm

[Table/Fig-5]: The mean value of the Foramen Transversarium (FT) measurements in right and left side of males and females.

Ponticuli: When comparing gender and side variations, left sided female atlas vertebrae exhibited a higher prevalence of Ponticuli, including PP, PL, and posterolateral types, than other groups [Table/Fig-6].

Type of Ponticuli	Right male	Left male	Right female	Left female	Right	Left
Complete PP	3 (3%)	2 (2%)	1 (1%)	2 (2%)	4 (2%)	4 (2%)
Incomplete PP	10 (10%)	15 (15%)	7 (7%)	14 (14%)	17 (8.5%)	29 (14.5%)
Complete PL	0	0	1 (1%)	0	1 (0.5%)	0
Incomplete PL	0	0	2 (2%)	2 (2%)	2 (1%)	2 (1%)
Complete posterolateral Ponticuli	1 (1%)	0	0	0	1 (0.5%)	0
Incomplete posterolateral Ponticuli	0	0	0	1 (1%)	0	1 (0.5%)
Complete PP and incomplete PL	0	0	0	1 (1%)	0	1 (0.5%)
Incomplete PP & complete PL	0	1 (1%)	2 (2%)	0	2 (1%)	1 (0.5%)
Absent	86 (86%)	82 (82%)	87 (87%)	80 (80%)	173 (86.5%)	162 (81%)

[Table/Fig-6]: The morphology of Ponticuli on the right and left side of male and female variables. Values presented as n (%).

Among 100 male atlas vertebrae, bilateral Ponticuli were present in 11% ($n=11$), unilateral Ponticuli in 10% ($n=10$), and absent in 79%. In 100 female vertebrae, bilateral Ponticuli were observed in 9% ($n=9$), unilateral in 15% ($n=15$), and absent in 76% ($n=76$). The overall prevalence of ponticulus was 22.5% ($n=45$), with a slightly higher incidence in females (24%) than in males (21%).

On One-way analysis of FT parameters such as AP diameter, and transverse diameter, no statistically significant association was found with Ponticuli in male atlas vertebrae, although some differences were noted. Similarly, no significant association was observed between right-sided Ponticuli and FT parameters in males. In contrast, female atlas vertebrae demonstrated a statistically significant association between right Ponticuli and the left transverse diameter of the FT ($p = 0.031$). A reduction in the left transverse diameter was noted in cases with complete posterolateral Ponticuli, incomplete PP, and complete PL. In male vertebrae, the association between right-sided PP and the right AP diameter of the FT approached significance ($p = 0.056$) [Table/Fig-7]. A Chi-square test was used to find the association between the types of FT and the presence or absence of Ponticuli. There was no significant association between the types of FT and Ponticuli [Table/Fig-8].

DISCUSSION

The prevalence of Ponticuli in present study was 22.5%. According to the study by Tambawala SS et al., the incidence of Ponticuli was 15.8%. The incidence of Ponticuli in males was 13.1% and in females 17.9% [12].

Morphometric parameter of Foramen Transversarium (FT)	Right Ponticulus Posticus (PP)		Left Ponticulus Posticus (PP)	
	Male (p-value)	Female (p-value)	Male (p-value)	Female (p-value)
Anteroposterior FT (Right)	0.056	0.776	0.056	0.261
Anteroposterior FT (Left)	0.766	0.333	0.864	0.833
Transverse FT (Right)	0.788	0.813	0.987	0.252
Transverse FT (Left)	0.256	0.031	0.150	0.521

[Table/Fig-7]: One-way ANOVA showing the association between Ponticuli and the morphometric parameters of the Foramen Transversarium (FT) according to side and gender.

Side	FT morphology	PP present	PP absent	Chi-square value	p-value
Right	Type I	4 (14.8%)	41 (23.7%)	2.102	0.552
	Type II	0	3 (1.7%)		
	Type III	4 (14.8%)	16 (9.2%)		
	Type IV	0	0		
	Type V	19 (70.4%)	113 (65.3%)		
Left	Type I	15 (39.5%)	36 (22.2%)	5.961	0.202
	Type II	0	4 (2.5%)		
	Type III	2 (5.3%)	10 (6.2%)		
	Type IV	21 (55.3%)	109 (67.3%)		
	Type V	0	3 (1.9%)		

[Table/Fig-8]: Chi square test showing association between the morphology of Foramen Transversarium (FT) and the presence or absence of Ponticuli. Values presented as n (%).

Side-wise analysis showed that Ponticuli posterior was more common on the left, while Ponticuli lateralis and posterolateral types were more prevalent on the right. According to Tudose RC et al., these variations may be due to differences in vertebral artery patterns or asymmetric mechanical loading, which can influence surrounding bony structures [13].

Tripodi D et al., reported a 28.24% prevalence of Ponticuli in the Italian population, with higher incidence in males, and recommended considering Ponticuli in children with craniofacial pain [Table/Fig-9] [12,14].

Authors	Sample size	Total prevalence	Male prevalence	Female prevalence	Study location
Tambawala SS et al., [12]	500	15.8%	13.1%	17.9%	Indian
Tripodi D et al., [14]	524	28.24%	35.27%	21.42%	Italian
Present study	200	22.5%	21%	24%	Indian

[Table/Fig-9]: Comparison of prevalence of Ponticuli with other studies [12,14].

According to Aziz JN et al., the most common morphology was the round variety (54%) and oval variety is the less prominent (29.6%) [15]. Irregular type was found among 10.4%, and quadrangular type was about 5.8%. Double foramina, incomplete foramina, and accessory foramina were also observed. In the present study, the type 5 variety, that is the oval type from right to left axis, is the highest frequency.

According to Hingmire VK et al., the round variety of FT was higher with 55%, and oval was 45%, incomplete and accessory foramina were also observed [16].

In the study by Deepa G et al., the FT of all the cervical vertebrae was measured. The mean AP diameter was 5.13 ± 1.25 mm on the right-side and 5.08 ± 1.11 mm on the left side. The transverse diameter on the right-side was 5.54 ± 1.11 mm, and on the left side was 5.42 ± 1.07 mm [11]. According to Taitz C et al., the morphology and morphometry of dry cervical vertebrae were studied. The anteroposterior diameter of the right and left FT of the atlas was 7.26 ± 0.87 mm and 7.23 ± 0.98 mm, respectively. The transverse diameter of the right and left FT of the atlas was 5.52 ± 0.93 mm and 5.76 ± 0.76 mm, respectively [10].

According to Periyasamy V et al., they compared the morphometric parameters of dry bone and CT images. They found a significant difference between the dry bone measurements and CT scan images [17].

Limitation(s)

The present study has several limitations. The sample size was relatively small, comprising 200 atlas vertebrae selected using convenience sampling, which may have introduced selection bias. As the study was conducted in a specific population from Tamil Nadu, the findings may have limited generalisability to other geographic and ethnic populations. Furthermore, the findings were not correlated with the clinical conditions of the individuals, and age-related variations in the morphology and prevalence of Ponticuli were not analysed.

CONCLUSION(S)

The present study demonstrates that Ponticuli and variations in the morphology and morphometry of the FT are common anatomical findings in the atlas vertebra. Although no significant overall association was observed between the presence of Ponticuli and the morphology or morphometry of the FT, the findings suggest that these structures may develop independently despite their close relationship with the vertebral artery.

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