DETAILED MORPHOMETRIC & MORPHOLOGICAL DESCRIPTION OF FORAMINA TRANSVERSARIUM OF ATLAS VERTEBRA

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Abstract

Background: Atlas, atypical cervical vertebra possesses Foramina transversarium (FT), a cardinal feature perusing numerous morphological variations with great clinical importance. So, the aim of our current study was to investigate the morphological features including a detailed morphometry of foramina transversarium of atlas among North Indian population.

Materials & methods: The current anatomical observational study was carried on 55 adult dry atlas both sexes from the department of Anatomy, SGT University, Gurugram. Detailed morphometry of FT like antero-posterior distance (APD) & transverse diameter (TD) was measured including inter foraminal distance (IFD) by a digital vernier caliper. Morphometry was conducted for vertebral foramen also. Morphological variability such as shape, completeness, absence or duplication of foramina was also examined by visual inspection Data obtained from the observation was tabulated and frequency analysis was performed.

Results: The mean values of morphometric parameters on right & left sides were: Antero posterior distance 6.93mm & 6.65 mm; Transverse diameter was 5.40 mm & 6.32 mm respectively and Inter foraminal distance was 24.23 mm. The Antero posterior distance & transverse diameters of vertebral foramen was 29.61 mm, 14.06 mm & 22.78 mm. Most frequent morphological shape of FT was oval (51%) followed by rounded (34%) & least was quadrangular (14%). The incidence of oval FT was predominant with 20% of incomplete foramina. Accessory foramina were observed in 9.09% & only 1.8% presented with absence of FT.

Conclusions: As FT of atlas shows tremendous morphological variability, so our detailed morphometry & morphological evaluation of FT among North Indian population will be a great help for the clinicians especially neurosurgeons to diagnose & treatment of upper cervical spine pathologies to relieve patients with vascular insufficiencies.

Keywords: Atlas; foramina transversarium, vertebral foramen; morphometry; morphologic features

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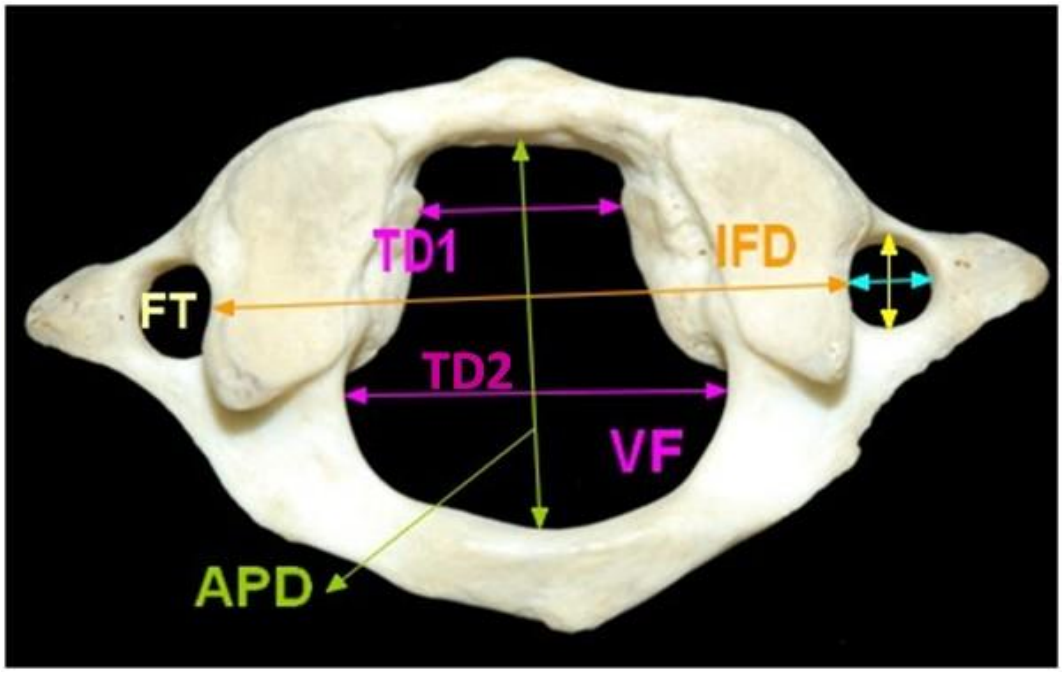
Introduction

Cervical vertebrae contribute the cranial most part of the vertebral column, one of the most vulnerable parts for spinal injuries leading to numerous clinical symptoms.[1] Foramina transversarium (FT) is one of the cardinal features of all cervical vertebrae having several morphological variations [1]. Atlas, the first cervical vertebra is an annular structure without a conventional vertebral body & spine. [1] FT, the unique feature of cervical vertebrae exhibits numerous morphological variations. This foramen is formed due to the special embryological origin of cervical vertebrae, a result of vestigial costal element fused with the body & true transverse process of the vertebra. [2] The vertebra basilar structures; vertebral vessels along with nerves can get entrapped between the bony parts. Abnormalities of vascular & neural structures along with bony deformities can lead to vertebra basilar insufficiencies. [3, 4] Normally this foramen is bounded anteriorly & posteriorly by the anterior & posterior roots respectively and laterally they are joined together by costotransverse bar or intertubercular lamella. [5, 6] Morphological variations are quite commonly seen in this bony aperture which might be due to many reasons such as developmental or mechanical. [7] The course of vertebral artery & vein depend on it, so it holds great clinical importance especially for neurosurgeons. [8] Along with vertebral vessels, the sympathetic nerves also run through this anatomical landmark, hence morphometric & morphological disparities may affect the vascular supply to the brainstem, cerebellum & other structures present in the posterior cranial cavity. [3, 4] Though single foramen on both sides of transverse process of atlas is most commonly seen, but accessory foramen, absence or incomplete foramen might be observed which can become a cause for symptoms related to vascular insufficiencies like syncope or headache. [5] Morphological variability including the bony spur in foramina trannsversaria can lead to neurological disturbances like compression neuropathy as nerve plexus passes through it. [9] Variability in size, shape & numbers even absence of foramina transversarium were reported among all cervical vertebrae as a whole in previous literature among different population groups. In the previous literature, narrow, multiple, under developed, double or triple foramina in the cervical vertebrae have been described & were associated with neurological manifestations like headache, fainting along with hearing impairment. [10, 11] To the best of our knowledge, few studies have been conducted on FT of first cervical vertebrae which is itself different from other cervical vertebrae. Also, FT of atlas possesses lots of clinical importance, so morphometric & morphological variability will be a great help for the surgeons performing various treatment modalities. [12, 13] Spinal cord compression especially in the cervical region may lead to full blown neurological signs & symptoms due to unusual bony or soft tissue components. [14] So, not only FT but also vertebral foramen of atlas also plays a major role as a bony factor for the pathogenesis of various neurological consequences. The knowledge of this osteometric evaluation will act as a limelight for neurosurgeons while performing cervical spine surgeries as well as surgeries of posterior cranial cavity structures. To the best of our knowledge, very few studies have been conducted exclusively on FT of atlas among North Indian population. So, it is expected that our current data on atlas will act as a reference media among North Indian population & will also be a great help for the clinicians especially neurosurgeons to enhance their knowledge regarding anatomical variations of FT in upper cervical region.

Materials & methods

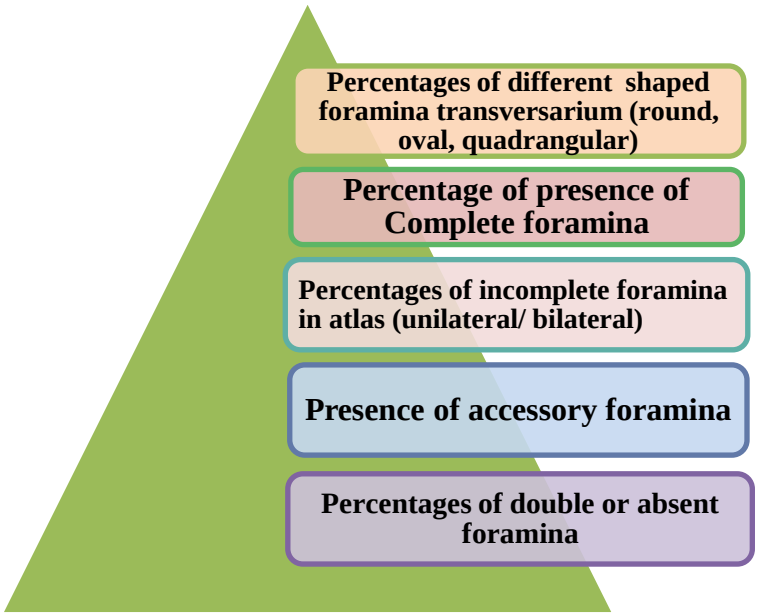
The current anatomical observational study included fifty five (55) dry adult human first cervical vertebrae or Atlas of unknown sexes obtained from department of Anatomy, SGT University, Gurugram over a period of one year. Only the bones devoid of any traumatic or gross deformities included as study materials. The exact age of atlas were not known, but were estimated as the mature adult individuals. The specimens were anonymised, randomly coded and de- linked from any identity sources. Each of the bones was observed for the general anatomical features suggestive of 1st cervical vertebra. The details of foramina transversarium (FT) as the cardinal feature of cervical vertebrae were conducted. Morphometric parameters like Antero- posterior (A- P) distance vertically & transverse diameter from medial to lateral side (M- L) were measured for foramina transversarium of all atlas on both right & left sides. The distance between the two foramina of all vertebrae was also noted as Inter-foraminal distance (IFD). All the measurements were taken by the help of a digital vernier caliper in millimeters (in mm).

The morphometric parameters were taken for the vertebral foramen also; Maximum vertical diameter as Antero posterior diameter (APD) & Transverse diameter at the anterior part (TD 1) and at the middle (TD 2) by the help of digital vernier caliper in mm. The parameters that have been measured in the atlas are displayed in Table/ Fig 1.



Table/ Fig 1: The foramina transversarium has been marked as **FT**. Antero posterior diameter (yellow closed arrow) & transverse diameters (blue closed arrow) have been shown in inside the FT. Inter foraminal distance **(IFD)** is marked as orange closed arrow. The big vertebral foramen has been presented as **VF**. Antero posterior diameter **(APD)** shown in green closed arrow & transverse diameters **TD1 & TD2** in purple closed arrow have been placed in the atlas.

Incidence (calculated in percentages %) of various morphological features of FT which has been mentioned in the following chart were also observed by visual inspection.



Statistical analysis

All the morphometric parameters were measured two times to reduce error & the average was taken for analysis. Data obtained from the study was tabulated in Microsoft Excel & maximum, minimum, mean with standard deviation for the each parameter were calculated and presented according to the side of the bones. The incidence was calculated in percentages for each of the morphological features observed among the study materials.

Results

In the current anatomical observational study, 55 atlases (1st cervical vertebrae) were examined for the morphometric evaluation of foramina transversarium as well as vertebral foramen. The maximum, minimum, mean with standard

deviation of each morphometric parameters of FT including inter- foraminal distance (IFD) in mm have been displayed in Table/ Fig 2. The morhometry of vertebral foramen of all atlases have been shown in Table/ Fig 3.

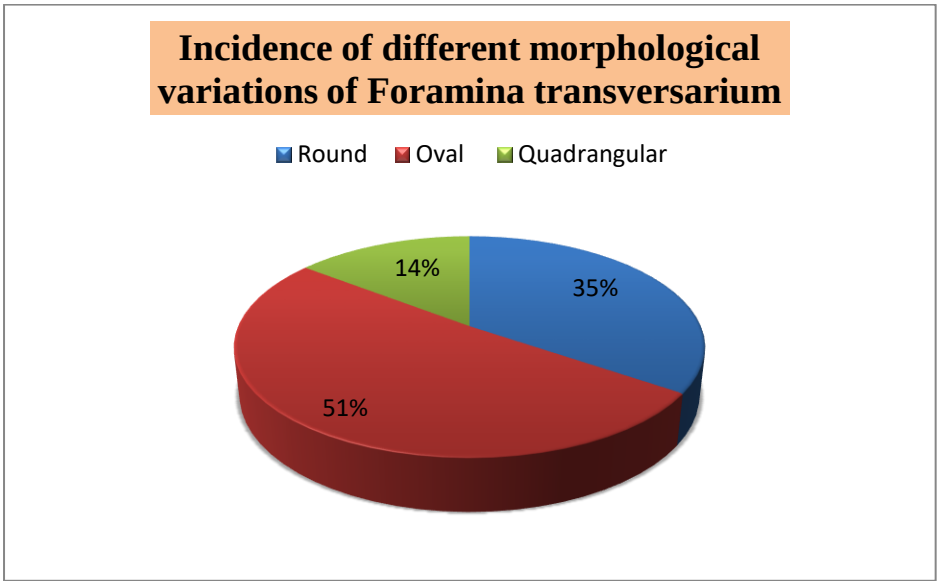
The morphological variants of FT were distributed according to their shape as round; oval or quadrangular were also noted & the incidence was presented in Table/ Fig 4 & 5. Their presence was also noted according to the sides (Table/ Fig 6). The presence of incomplete, double, accessory FT was also observed and their incidence was calculated in percentages which have been mentioned in Table/ Fig 7 & 8.

Total sample & population	Parameters of Foramina transversarium	Side	Maximum (in mm)	Minimum (in mm)	Mean (in mm)	Standard deviation
Fifty five (55) Atlas & North Indian	APD	Right	9.33	4.32	6.93	1.412
		Left	8.41	4.45	6.65	1.105
	TD	Right	8.52	3.14	5.40	1.113
		Left	7.46	2.86	6.32	0.945
	Inter foraminal distance IFD)-		29.48	20.02	24.23	2.720

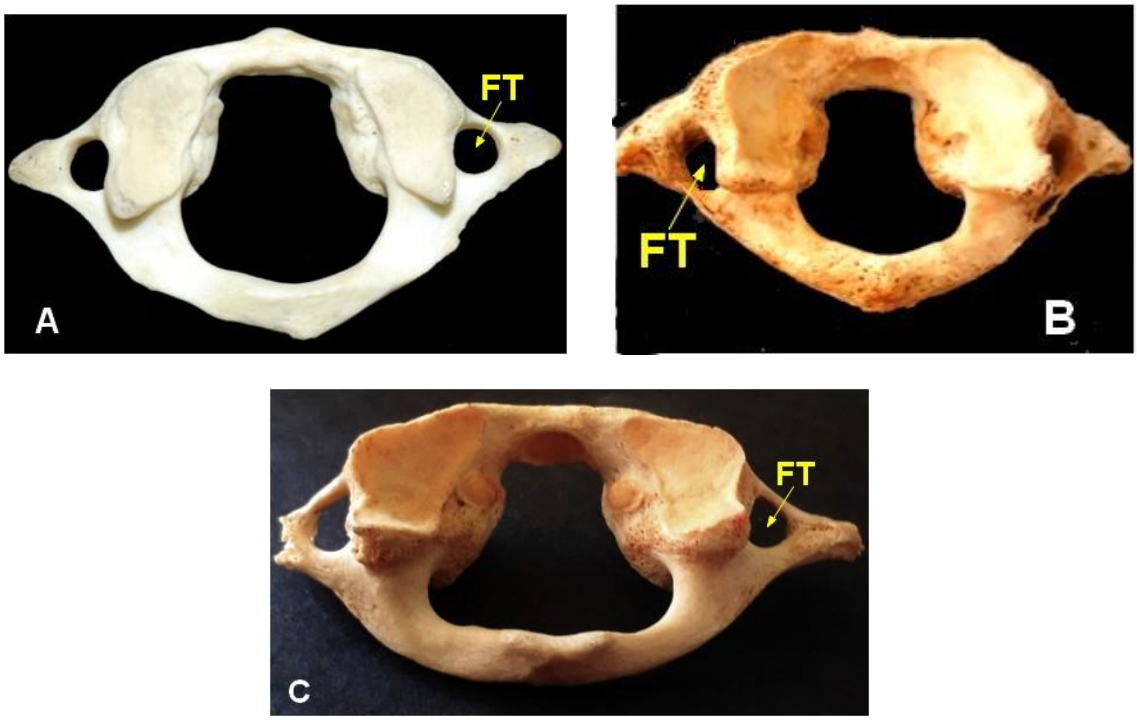
Table/ Fig 2: Morphometric parameters of foramina transversarium including inter- foraminal distance (IFD) in mm

Total sample & population	Parameters of Vertebral foramen	Maximum (in mm)	Minimum (in mm)	Mean (in mm)	Standard deviation
Fifty five (55) Atlas & North Indian	A-P distance	34.91	25.61	29.61	2.448
	Transverse diameter (upper part)	17.65	11.36	14.06	1.316
	Transverse diameter (at the middle)	31.03	16.78	22.78	3.338

Table/ Fig 3: Morphometry of Vertebral foramen (VF) in mm



Table/ Fig 4: Incidence of morphological variants of FT according to the shape



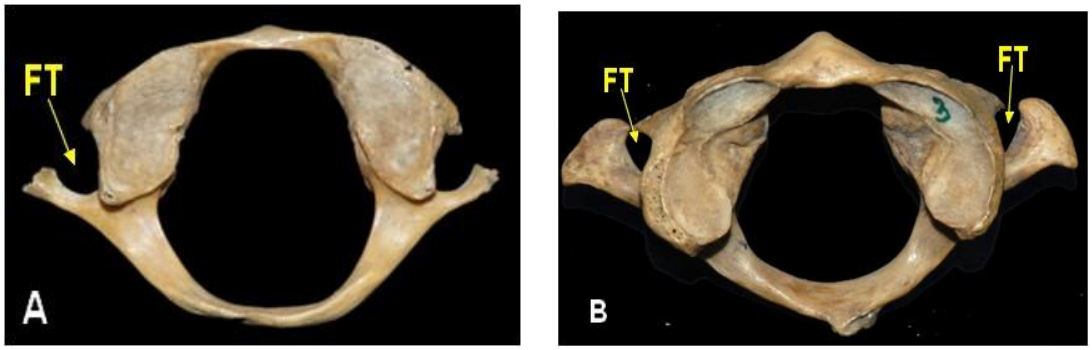
Table/ Fig 5: Images exhibiting different varieties of FT which has been marked as yellow arrow according to the shape (A: Rounded FT; B: Oval shaped FT & C: Quadrangular FT)

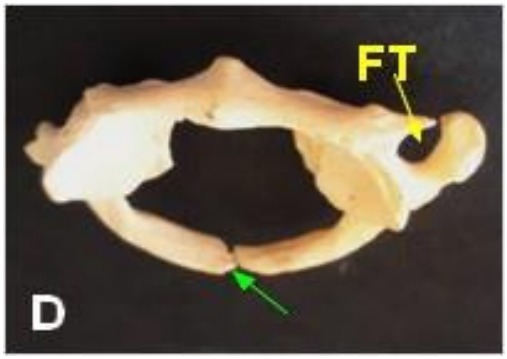
Shape of foramina transversarium	Side				Total	
	Right		Left		Both sides	
	n	%	n	%	n	%
Round	7	36	12	63	19	34
Oval	12	42.8	16	57.1	28	51
Quadrangular	5	62.5	3	37	8	14

Table/ Fig 6: Frequency distribution of Foramina transversarium (FT) according to the sides

Morphological features of foramina transversarium	n of bones	%
Incomplete foramen	11	20
Unilateral incomplete foramen	4	7.2
Bilateral incomplete foramen	7	12.7
Double or accessory foramen	5	9.09
Absent foramen	1	1.8
Total numbers of bones with morphological variations	17	30.9

Table/ Fig 7: Frequency distribution of Morphological variations of FT in terms of incomplete foramina, double or accessory foramina & absent foramina among atlas





Table/ Fig 8: Morphological variations of FT in terms of incomplete foramina marked in yellow arrow (A: incomplete bilateral semicircular foramina; B: incomplete U shaped foramina bilaterally present; C: Unilateral hemi circular FT with a quadrangular FT on the other side; D: Incomplete unilateral U shaped foramen with posterior arch deficiency in green arrow)

Table/ Fig 9: Presence of accessory foramen of atlas (A: Unilateral accessory foramen in yellow arrow & B: Unilateral accessory foramen near posterior arch which has been displayed by the help of a metal probe).

Apart from this, In our observation, the presence of double FT was absent. Absence of foramina transversarium was not identified in the present study. Their incidence was also calculated and proper photography was done for the documentation.

Discussion

Atlas, the first cervical vertebra having a complex structural organization & plays a great role in the movement of head & neck. [15] Atlas, the cranial most part of the vertebral column is having an anterior as well as a posterior arch instead of a conventional vertebral body. There is a groove on the superior surface of its posterior arch to pass the vertebral artery and suboccipital nerve (first cervical spinal nerve). [1] Posterior atlanto- occipital membrane is attached to upper border of posterior arch but it is deficient on its lateral part through which vessels & nerve traverse. The oblique ligament of atlas located at the inferior border of this membrane span over the vertebral artery groove. Occasionally it might get ossified and convert groove into a foramen; complete or partial act as an accessory foramen. [16, 17] These foramina are termed as ponticulus posterior or arcuate foramen; also known as retroarticular canal, foramen retroarticular superior or retrocondylar bony foramen. [18] The third part of vertebral artery passes from Ft of atlas, twig at the back & medial side; and finally lies on the posterior arch of atlas. Sometimes, ponticulus lateralis might be present alone or together with ponticulus posterior. [6] All these structural variations might lead to damage or distortion of vertebral artery followed by vertebrao basilar insufficiency. [19] In severe cases, they cause reduced vascular supply to the inner ear leading to hearing disturbance along with other neurological compression syndrome. [10, 11] FT is formed by vestigial costal element fused to the body & the true transverse process [20] & act as the gateway to pass vertebral vessels & sympathetic ganglion from inferior cervical ganglion. [2] The two vertebral arteries fused to form basilar artery which supply thee posterior part of brain. [21] The tortuous course of vertebral artery along with bony abnormalities of FT may result serious cervical decompression. [22] So, the course of vertebral vessels determines the formation of foramina transversarium & structural abnormalities of vessels can lead to developmental anomalies of FT. [3, 13]. It has been also observed that, absence of FT due to absence of vertebral vessels. [23] Even at times, FT may get divided into a larger foramen and a smaller accessory foramen. [24, 25] But in this scenario the bigger anterior foramen becomes narrower than the posterior one

leading to compression syndrome. So, the morphometry of FT is fundamental for the clinicians especially neurosurgeons to find out the pathogenesis of clinical features suggesting vertebra basilar insufficiencies.

In our present observation, the A- P length of FT was almost similar on both sides of atlas which was 6.93mm & the transverse length on right and left was 5.4 mm & 6.3 mm respectively among North Indian population. Our result was almost similar as study was undertaken among Thais population by Aarda et al.. [26] On the other hand, among Israel & South Indian population the A- P length was much higher than our observation [6, 27] (Table/ Fig 10). We have also measured the IFD which was 24.23 mm which was measured in very few previous observations. Among South African population it was measured in typical cervical vertebrae which were 27.91 mm in males & 26.83 mm in females; though we have not done measurements on sexual dimorphism. [28]

Though FT is a noticeable landmark of all cervical vertebrae starting from atlas; so, structural annotation like incompleteness, accessory or under develop FT may be related to the neurovascular abnormalities. Previous studies have been demonstrated FT with incompleteness or underdevelopment; even presence of multiple or triplicate FT among various population groups. Even in a study by A H Zibis et al. among Indo-European population, narrow; multiple; underdeveloped & triple foramina were observed [29] but it was conducted among all cervical vertebrae. In our study, we have exclusively observed atlas for morphological variations of FT. In our observation, accessory foramina were seen in 9 % of atlas among 55 total vertebrae which was similar to study done by Nagar et al. [30] & Srobar et al. [13]. But very high incidence of accessory FT was observed in studies done by Kaya et al. [4], Aziz et al. [12]., Rao BS et al.[31] among different population group. The frequency of accessory FT was very high among Egyptian [12] & Jeweish [4] population. Very low incidence was observed among Das et al. study in 2005. [3] Though incidence was calculated for accessory FT among cervical vertebrae by many authors but very few studies were undertaken only on atlas among North Indian population which has been displayed in Table/ Fig 11.

In our study, underdeveloped or incomplete FT was demonstrated on 20% of atlas & was more frequently seen bilaterally. Only 1.8% atlas in our observation showed absence of FT. We did not observe atlas with triplicate FT in our study.

Many reasons have been stated for such morphological picture of FT, but among all congenital; genetic; bridging with ossification of oblique ligament of atlas & mechanical factors especially among laborers. [6, 33, 34] According to sexual dimorphism, it was also noticed that complete FT was much more commonly seen among females as compared to males [9] & Paraskevas et al. [35] found a higher incidence of incomplete FT among 5- 44 years of age. Even bilateral arcuate foramen has been also reported in the previous study by Piplani et al. [36] in 2013.

In our observation among 55 atlas, most commonly seen shape of FT was oval (51%) followed by rounded & only 14% was quadrangular. We did not categorize FT as irregular. But it was 54% rounded with 5.8% quagrangular shaped in study performed by Joseph et al.[12] & other studies like Rekha et al.[27] & Aung et al.[28] most commonly seen shape was oval followed by rounded as seen in our result; these morphological variability have been demonstrated in the table/ Fig 12.

Authors	Population	No of atlas	Parameters (in mm)				
			Right side		Left side		
			Antero posterior diameter (APD)	Transverse diameter (TD)	Antero posterior diameter (APD)	Transverse diameter (TD)	Inter-foraminal distance (IFD)
Traitz et al. [6]	Israel	33	7.26	5.52	7.23	5.76	
Rekha et al. [27]	Karnataka	153	7.92	6.32	7.8	6.32	
Arada et al. [26]	Thais	107	7.03	5.4	6.91	5.72	
Present study	North India	55	6.93	5.4	6.65	6.32	24.23

Table/ Fig 10: Morphometric parameters of foramina transversarium including inter- foraminal distance (IFD) in mm among various other studies

Authors	Year	Population	Sample size	Type of cervical vertebrae	Accessory foramina transversarium		
					Total (%)	Unilateral (%)	Bilateral (%)
Traitz et al.[6]	1978	Israel	480	All		34	
Nagar et al. [30]	1999	Indian	1388	All	8.6		
Das et al. [3]	2005	Indian	132	All	1.5		
Kaya et al. [4]	2011	Jewish	262	All	22.7		
Rekha B S et al.[27]	2014	Karnataka	153	Atlas	6.54		
Jawed et al.[15]	2015		174	All	14.36	2.87	11.49
Rao B S et al.[31]	2016	Telengana	50	Atlas	20		
Srobar G et al.[13]	2017	Srinagar	100	All	9	5	4
Aziz J A et al.[12]	2018	Egypt	135	Atlas	17.70		
Aung et al. [28]	2020	Turkey	All	86			
Aarda et al. [26]	2020	Thais	All	107		8.4	25.5
Present study	2021	North Indian	Atlas	55	9.09	4	5

Table/ Fig 11: Incidence of accessory FT among various other population groups

Authors (year)	Population	Sample size (atlas)	Shape of FT						
			Rounded %	Oval				Irregular %	Quadrangular %
				%	%	%	%		
Traitz et al.[6] (1978)	Israel	25	20	20	0	24	24		
Rekha BS et al.[27] 2014	Karnataka	153	7.26	39.9	1.98	50	2.64		
Joseph Aziz et al.[12] (2018)	Egypt	135	54.1	29.6				10.4	5.8
Arada et al.[26] (2020)	Thais	107	23	69	-	2.83	3.7		
Present study (2021)	North Indian	55	35	51				-	14

Table/ Fig 12: Morphological variability regarding different shapes of FT demonstrated in the previous studies

Along with detailed morphometry & morphology of FT, we have also performed morphometry of vertebral foramen in all atlas. But the A- P length of VF was 29 mm which was lesser than study performed by Sharma et al.[32] Also, the breadth of VF in our study came little higher than Sharma et al. result; though they measured only in a few samples of atlas. It has been observed that FT of atlas shows a tremendous morphological variability among Indian population also which has been exhibited in very few previous studies. So, this type of anatomical variations should be kept in mind while clinical examinations & radiographic evaluations of neurological cases.

Conclusions:

It is expected that, our detailed anatomical morphometric & morphological study on foramina transversarium of atlas will help the clinicians especially neurosurgeons to correlate the association of symptoms suggesting of vertebrobasilar insufficiencies. This will be a great help for them to decide & perform treatment modalities, mainly for cervical spine surgeries to relieve the patients from neurological deficiencies.

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