Innovations

Prevalence and Dimensions of Arcuate Foramen of Human Atlas Vertebrae and their Clinical Implications – An Anatomical Observational Study

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Abstract

Introduction: *The arcuate foramen, also known as ponticulus posticus or Kimmerle's anomaly, is formed by ossification of the posterior atlantooccipital membrane over the vertebral artery. This anomaly occurs in 3–15% of the population, with a higher prevalence in females. Bony bridges are formed along the vertebral artery groove. The arcuate foramen connects the superior articular facet to the posterior arch of the atlas, forming the arcuate foramen. The third part of the vertebral artery can be compressed by the arcuate foramen during its course, potentially causing vertebrobasilar insufficiency. This study aimed to determine the frequency of the arcuate foramina in Andhra Pradesh, India, to understand vertebral artery entrapment.* ***Materials and methods:*** *A cross-sectional observational study was conducted using 70 dry adult human atlas vertebrae, with age and sex unspecified. This study focused on examining the prevalence of the arcuate foramen located behind the lateral mass of the atlas vertebra. Measurements were taken for the arcuate foramen using a digital vernier caliper. Data were statistically analyzed using IBM SPSS Version 21.* ***Results:*** *The overall prevalence of the arcuate foramen in the present study was 18.57%. The prevalence of a complete arcuate foramen was 7.14%, and that of a partial arcuate foramen was 6.43%. The mean values of the anteroposterior and superoinferior of the arcuate foramen were 6.90±0.43 mm and 5.83±0.27 mm on the right side, respectively, and 6.98±0.31 mm and 5.71±0.13 mm on the left side, respectively.* ***Conclusion:*** *Vertebral artery compression within the arcuate foramen can reduce blood flow during extreme head rotation. Orthopedic surgeons, neurologists, radiologists, and physicians should be familiar with arcuate foramen variations. Clinicians must consider complete arcuate foramen when symptoms indicate vertebral artery compression. Preoperative screening for arcuate foramen is recommended prior to craniovertebral junction surgery. Further research is needed to establish the clinical relevance of the arcuate foramen.*

Key words: *Arcuate foramen, Atlas vertebra, Craniovertebral junction, Transpedicular screw, Vertebral artery, Vertebrobasilar insufficiency.*

Introduction:

The atlas, or the first cervical vertebra (C1), is responsible for supporting the skull at the top of the vertebral column and gives attachment to neck muscles. It is distinct because it lacks both the vertebral body and the spinous process. The centrum of the atlas is fused with the axis, forming the odontoid process of the axis vertebra. It comprises two lateral masses connected by a short anterior arch, a posterior arch, and two transverse processes. The superior surface of the posterior arch features a broad groove on each side, accommodating the third part of the vertebral artery and the first cervical spinal nerve, which are overhung by the lateral masses (1, 2).

The arcuate foramen is a common anatomical variation of the atlas, characterized by a bony bridge formed by ossification of the posterior atlantooccipital membrane over the passage of the vertebral artery (3). This structure is referred to by various names, including the posterior ponticleor ponticulus posticus, foramen arcuate atlantis, canalisvertebralis, Kimmerle's anomaly,retroarticular canal, and retrocondylar vertebral artery ring (4). This anomaly is observed in approximately 3–15% of the population (5). The articular foramen is more frequently found in females than in males (6), although some researchers have noted no significant difference in prevalence based on age and sex (7).

Bony projections frequently emerge from the anterior and posterior edges of the vertebral artery groove, forming bridges that can be located posteriorly, laterally, or posterolaterally. The ponticulus posticus, also known as Kimmerle's anomaly, is a bony bridge that connects the superior articular facet to the posterior arch of the atlas, creating a retroarticular canal or an arcuate foramen when fully formed. The lateral bridge is a lateral bone extension that connects the lateral edge of the superior articular facet to the posterior root of the transverse processes of the atlas and potentially appears as a supratransverse foramen. The ponticulus posterolateralis is a wide bone fragment that stretches from the lateral edge of the posterior third of the superior articular facet to the transverse process and dorsal edge of the vertebral groove of the atlas.

The third part of the vertebral artery exits the foramen transversarium of the atlas, curves backward and inward behind the lateral mass of the atlas, and rests in the neurovascular groove on the posterior arch of the atlas. It then passes through the opening in the anterior part of the posterior atlanto-occipital membrane and enters the foramen magnum. As the vertebral artery moves from the foramen transversarium to the cranial cavity, it is vulnerable to damage or deformation from external factors, such as bony or ligamentous structures, such as the arcuate foramen, which can apply external pressure on it (8). Compression of the vertebral artery may result in vertebrobasilar insufficiency (9).

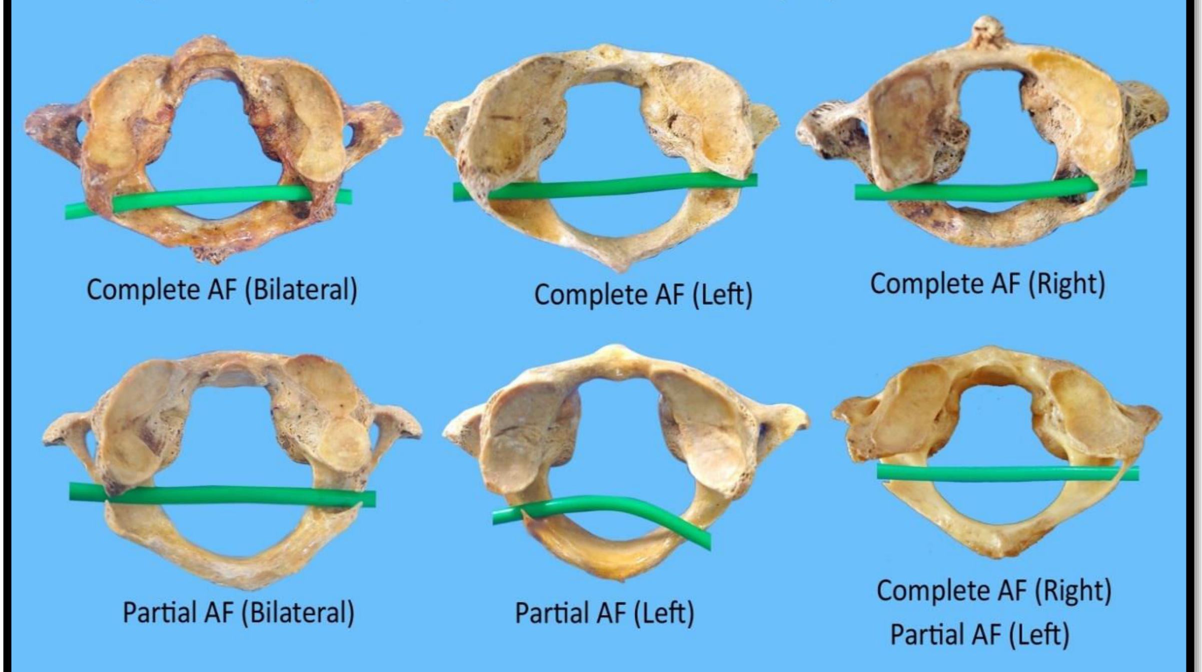
Transarticular and transpedicular screw fixation are common methods for stabilizing the cervical spine. However, incorrect placement of pedicle screws can lead to damage in the upper cervical region of the spine. Therefore, avoiding damage to the vertebral artery in the arcuate foramen is crucial. Iatrogenic trauma to the vertebral artery can affect nearby critical structures, including the spinal cord, nerve roots, cranial nerves, and vertebral arteries (10).

This study aimed to determine the frequency and dimensions of the arcuate foramina in the population of Andhra Pradesh, India. Understanding these variations may help clarify the link between the arcuate foramina and vertebral artery entrapment.

Materials and Methods:

An observational cross-sectional study was conducted at the Department of Anatomy, Konaseema Institute of Medical Sciences and Research Foundation, Amalapuram, India. The study involved 70 dry adult human atlas vertebrae of unspecified age and sex, which were obtained from a bone bank within the Anatomy Department. Vertebrae that were damaged or deformed were excluded from the study. This study focused on examining the prevalence of the arcuate foramen located behind the lateral mass of the atlas vertebra (Figure 1).

Figure 1: Complete and partial arcuate foramen (AF) of Atlas Vertebra



The classification described by Hasan et al. (4) for the groove of the vertebral artery was used to examine, identify, and categorize arcuate foramina.

Type 1, where a noticeable impression of the vertebral artery is present on the posterior arch.

Type 2, where the vertebral artery impression is more pronounced.

Type 3, where a partial posterior ponticulus or bony spicule exists.

Type 4, where a complete posterior ponticulus is observed.

Type 5, where a lateral bridge extends from lateral mass to transverse process.

Type 6, where a more extensive posterolateral tunnel is identified.

Measurements were taken for the arcuate foramen, using a digital vernier caliper with an accuracy of 0.01 mm. The following parameters were observed, as shown in figure 2.

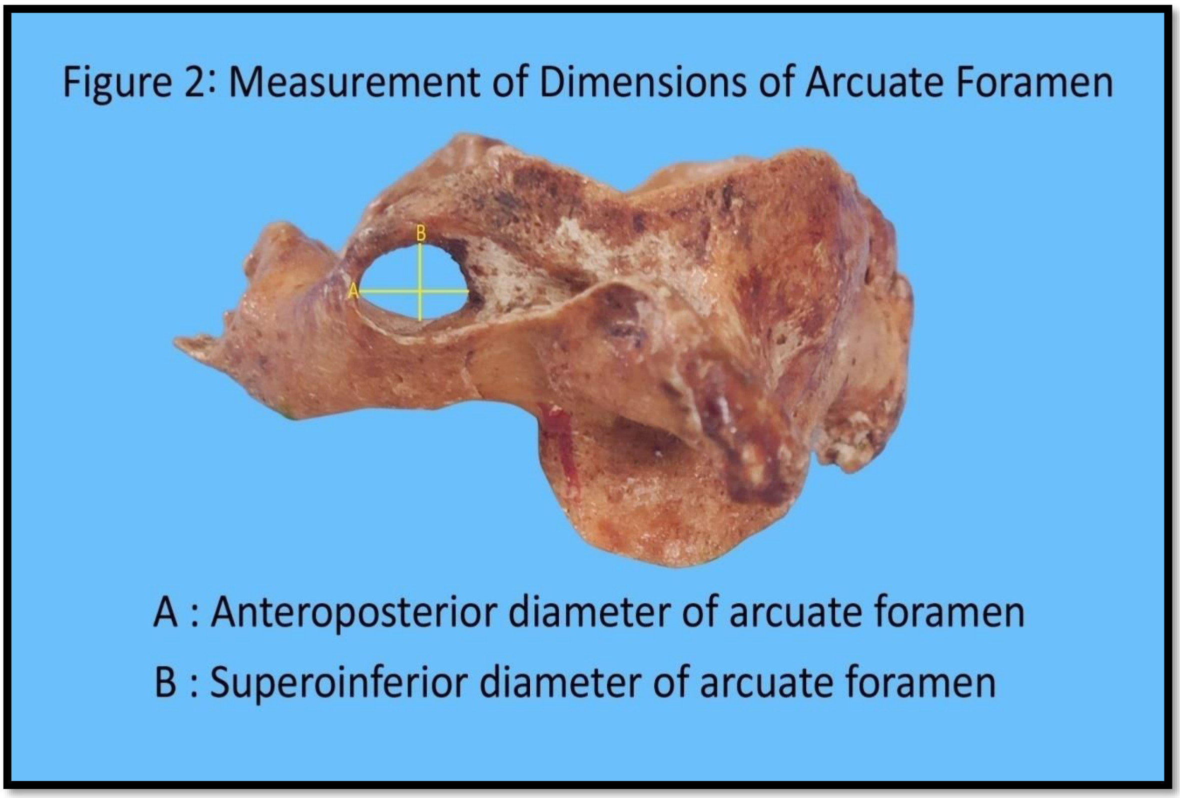


Figure 2: Measurement of Dimensions of Arcuate Foramen

- Anteroposterior diameter: This was measured as the maximum distance from the anterior margin to the posterior margin of the arcuate foramen.
- Superoinferior diameter: This was measured as the maximum distance from the superior margin to the inferior margin of the arcuate foramen.
- Cross-sectional area: This was calculated using the formula $\pi (D1 \times D2) \div 4$, where D 1 is the anteroposterior diameter and D 2 is the superoinferior diameter of the arcuate foramen.

Data analysis and visualization were performed using descriptive statistical techniques, such as mean, standard deviation, and percentage. Statistical analysis of the data obtained was performed using IBM SPSS Version 21. The results obtained in the current study were compared with those reported by various authors in their previous studies.

Results:

The results obtained from the examination for the identification and measurement of the dimensions of the arcuate foramen and in 70 dry human atlas vertebrae are recorded and shown in Tables 1, 2, and 3.

Table 1: Prevalence of complete and partial arcuate foramen in atlas vertebrae in the present study (N = 70)

S. No	Presence of complete or partial arcuate foramen	Number (70)	Percentage (%)
1	Vertebrae showing unilateral partial arcuate foramen	3	4.28
2	Vertebrae showing bilateral partial arcuate foramen	2	2.86
3	Vertebrae showing unilateral complete arcuate foramen	4	5.71
4	Vertebrae showing bilateral complete arcuate foramen	2	2.86
5	Vertebrae showing partial arcuate foramen on one side and complete arcuate foramen on other side	2	2.86
6	Total number of vertebrae showing either partial or complete arcuate foramen	13	18.57

Of the 70 atlas vertebrae examined, 13 vertebrae showed either a partial or complete arcuate foramen. Hence, the prevalence of the arcuate foramen in the present study was 18.57%. Among the 13 atlas vertebrae, 5 exhibited a partial arcuate foramen (3 unilateral and 2 bilateral), 6 exhibited a complete arcuate foramen (4 unilateral and 2 bilateral) and two vertebrae exhibited a partial arcuate foramen on one side and a complete arcuate foramen on the other side.

Table 2: Prevalence of various types observed in the present study accordingto the classification of the grooves for the vertebral artery described by Hasan et al. The right and left sides were recorded separately for 70 atlas vertebrae (N = 140)

S. No	Class of groove for vertebral artery	Number (140)	Percentage (%)
1	Type-1	72	51.43
2	Type-2	49	35.00
3	Type-3	9	6.43
4	Type-4	10	7.14
5	Type-5	0	0
6	Type-6	0	0

Among the 70 atlas vertebrae examined (N = 140, 70 right side and 70 left side), 51.43% exhibited Type 1, 35% exhibited Type 2, 6.43% exhibited Type 3 (partial arcuate foramen), and 7.14% exhibited Type 4 (complete arcuate foramen). Type 5 and Type 6 vertebrae were not observed in the present study.
The results obtained from the measurement of the dimensions of the arcuate foramen, such as the anteroposterior diameter, superoinferior diameter, and cross-sectional area, are shown in Table 3.

Table 3: Mean and standard deviation of the parameters observed for the right and left arcuate foramina in the present study

Parameter	Right side		Left side	
	Range (mm)	Mean±SD (mm)	Range (mm)	Mean±SD (mm)
Anteroposterior diameter	6.21-7.21	6.90±0.43	6.53-7.29	6.98±0.31
Superoinferior diameter	5.52-6.22	5.83±0.27	5.54-5.88	5.71±0.13
Cross-sectional area (mm^2)	26.05-34.08	30.64±2.20	27.49-32.30	30.37±2.09

The mean anteroposterior diameter of the arcuate foramen was 6.90±0.43 mm on the right side and 6.98±0.31 mm on the left side. The mean value of the superoinferior diameter of the arcuate foramen was 5.83±0.27 mm on the right side and 5.71±0.13 mm on the left side. The mean value of the cross-sectional area of the arcuate foramen was 30.64±2.20 mm on the right side and 30.37±2.09 mm on the left.

Discussion:
Atlas bridges, or ponticles, are bony outgrowths that develop on the groove for the vertebral artery in the atlas vertebra, converting it into either a partial or complete foramen, known as the arcuate foramen (11). The arcuate foramen was first reported by Macalister in 1869. Although several theories have been proposed about the formation of ponticuli, it remains uncertain whether they have a congenital or genetic origin. Some theories suggest that they result from the ossification of the oblique ligament, which spans the groove for the vertebral artery, as a consequence of aging (1). Taitz and Nathan (12) suggested that external mechanical factors, such as carrying heavy loads on the head, might influence the development of the arcuate foramen. They noted that bony ponticuli were more commonly observed in laborers than in non-laborers. Paraskevas G et al. supported this hypothesis by discovering that the canal for the vertebral artery is more commonly found in laborers compared to non-laborers (13). Le Double suggested that pulsation of the vertebral artery leads to ossification of the ligament. He also noted that ossification alone cannot fully explain the

phenomenon, as the development of the arcuate foramen is attributed to a regressive and disappearing morphological process (14).

Many authors have reported the prevalence of partial and complete arcuate foramina. The results obtained in the present study for the prevalence of partial and complete arcuate foramina were compared with the values recorded by various authors in their previous studies (Table 4).

Table 4: Comparison of the prevalence of complete and partial arcuate foramina in atlas vertebrae in the present study with those recorded by various authors in earlier research

S. No	Author	Complete Arcuate Foramen (% prevalence)	Partial Arcuate Foramen (% prevalence)
1	Sun JY 1990 (9)	7.40	--
2	Cakmak O et al. 2005 (15)	11.70	3.30
3	Paraskevas G et al. 2005 (13)	10.23	24.43
4	Krishnamurthy A et al. 2007 (16)	8.33	5.50
5	Tubbs RS et al 2007 (17)	5	--
6	Malukar et al. 2011 (18)	6.25	10
7	Baeesa SS et al. 2012 (19)	16.10	31.80
8	Seema et al. 2016 (20)	8	12
9	Santhi B et al. 2017 (21)	8.60	3.45
10	Present study 2025	7.14	6.43

The prevalence of the complete and partial arcuate foramen observed in the present study are 7.14% and 6.43%, respectively, which is similar to the values recorded by Sun JY but lower than the values recorded by Cakmak O et al., Paraskevas G et al., Krishnamurthy A et al., Baseesa SS et al., Seema et al., and Santhi B et al. but higher than those of Tubbs RS et al. and Malukar et al.

The results obtained in the present study for the prevalence of class of groove for the vertebral artery observed in the present study and those recorded by various authors in previous studies (Table 5).

Table 5: Comparison between the prevalence of class of groove for the vertebral artery observed in the present study and those recorded by various authors in earlier research

Class	Hasan et al. 2001 (4)	Santhi B et al. 2017 (00)	Present study 2025
Type-1	47.40%	18.97%	51.43%
Type-2	42.90%	41.38%	35.00%
Type-3	3.14%	33.62%	6.43%
Type-4	3.42%	4.31%	7.14%
Type-5	2.00%	0.86%	0%
Type-6	1.14%	0.86%	0%

The results obtained in the present study for the dimensions of the arcuate foramen, such as the anteroposterior and superoinferior diameters, are compared with those recorded by various authors in previous studies (Table 6).

Table 6: Comparison between the dimensions of the arcuate foramen measured in the present study and those recorded by various authors in previous studies

S. No	Author	Anteroposterior diameter (mm)	Superoinferior diameter (mm)
1	Zarna K Patel 2012 (22)	7.16	6.57
2	Kumar BS et al. 2016 (23)	8.8	7.7
3	Santhi B et al. 2017 (21)	6.09	5.44
4	Lalit M et al. 2019 (14)	8.79	5.98
5	Rahman MA 2022 (24)	7.5	5.7
6	Dubey A et al. 2023 (25)	7.0 – 7.5	4.0-6.0
7	Present Study 2025	6.90	5.83

The Mean values observed for anteroposterior diameter and superoinferior diameter of the arcuate foramen in the present study were 6.90 mm and 5.83 mm, respectively which were higher than the values recorded by Santhi B et al. but were lower than the values recorded by ZarnaKPatel, Kumar BS et al., Lalit M et al., Rahman MA and Dubey A et al.

Beyond the surgical viewpoint, the arcuate foramen presents numerous other clinical hazards, including compression of the vertebral artery, which can result in neurological issues such as vertebrobasilar arterial insufficiency (26). According to Mitchell, compressed vertebral arteries may lead to stenosis due to hyperextension of the head or manual pressure in this region (27). Cushing et al. (2001) provided clinical evidence indicating that the presence of an arcuate foramen increases the likelihood and occurrence of vertebral artery dissection within the arcuate foramen. This is mainly because the artery becomes tethered during trauma, particularly when the neck is rotated (28). These findings imply that the risk of vertebral artery injury in the presence of an arcuate foramen is largely influenced by the size and structure of the foramen.

The occurrence of an arcuate foramen has been linked to migraine without aura in patients who received chiropractic care. Although the exact mechanism remains unclear, it may be related to ischemic contraction of the vertebral artery or tension in the dura mater at the craniocervical junction. Additionally, the presence of an arcuate foramen can create the illusion of a larger dorsal arch, potentially misleading the clinicians. In such scenarios, a surgeon might mistakenly place a screw into the arcuate foramen, risking vertebral artery injury. This can result in stroke or even death due to embolism, thrombosis, or arterial dissection (29).

Therefore, it is accurate to assert that these anatomical differences should be explored and considered as possible differential diagnoses for persistent, orofacial pain. A documented link exists between the arcuate foramen and Barre–Lieou syndrome. This syndrome is characterized by headaches, pain behind the eyes, facial vasomotor disturbances, and issues with swallowing and speaking, all of which are due to changes in blood flow within the vertebrae and recurring vision problems (30). Consequently, the arcuate foramen is a potential anatomical variant of the atlas.

Conclusion:

During extreme head and neck rotation, the vertebral artery can be easily compressed within the arcuate foramen, leading to reduced blood flow. Therefore, it is important for orthopedic and neurosurgeons, neurologists, radiologists, physicians, and anthropologists to be aware of the presence and variations of the arcuate foramen. When symptoms suggest a major cause of vertebral artery compression, clinicians should consider the existence of a complete arcuate foramen or bony spicules. Awareness of these anomalies is crucial before performing surgical procedures on the atlas vertebra. We strongly recommend preoperative screening to identify the presence of an arcuate foramen when planning surgeries near the craniovertebral junction. Additional radiological and clinical research is necessary to emphasize the importance and clinical relevance of the arcuate foramen.

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