

Research Article



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Morphometric Evaluation of the Atlas Vertebra (C1) in Adult Humans

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Abstract

Background:

The atlas vertebra (C1) plays a crucial biomechanical role at the craniovertebral junction by supporting the skull and facilitating complex head movements. Owing to its atypical structure and close relationship with vital neurovascular elements—particularly the vertebral artery—detailed morphometric knowledge of the atlas vertebra is essential for safe surgical intervention, radiological interpretation, and anatomical understanding. **Aim:** The present study aimed to evaluate the morphometric parameters and morphological variations of the adult human atlas vertebra, with special emphasis on dimensions relevant to surgical procedures at the craniovertebral junction.

Materials & Methods: A descriptive statistical study was conducted on 150 dry adult human atlas vertebrae obtained from anatomy museums of medical colleges in northern India. Only intact vertebrae without deformity were included. Linear measurements were taken using a digital Vernier calliper with 0.01 mm accuracy. Parameters assessed included transverse width of the atlas, distances between medial and lateral margins of the foramina transversaria, dimensions of the vertebral canal, morphometry of the vertebral artery groove, presence of retroarticular canals (ponticulus posticus), and morphology of the superior articular facets. Data were analysed using descriptive and inferential statistics, with a p-value < 0.05 considered statistically significant. **Results:** The mean transverse width of the atlas vertebra was 70.51 ± 8.12 mm. The mean outer and inner distances between the foramina transversaria were 57.03 ± 4.75 mm and

39.03 ± 8.76 mm, respectively. The vertebral canal showed a mean anteroposterior diameter of 29.62 ± 2.03 mm and a transverse diameter of 26.57 ± 3.82 mm. The outer distance of the vertebral artery groove was significantly greater on the right side compared to the left ($p < 0.001$), while no significant side difference was observed in the inner distance. Incomplete retroarticular canals were more common than complete forms, and no bilateral complete ponticulus posticus was observed. Oval-shaped superior articular facets were the most frequent morphology, followed by kidney-shaped facets.

Conclusion:

The atlas vertebra demonstrates considerable morphometric variability and side-to-side asymmetry, particularly in dimensions related to the vertebral artery groove and articular facets. These findings underscore the importance of individualized anatomical assessment during surgical planning at the craniovertebral junction. The data generated provide valuable population-specific reference values that may enhance surgical safety, radiological evaluation, and anatomical education.

Keywords:

Atlas vertebra, C1 morphometry, vertebral artery groove, ponticulus posticus, craniovertebral junction, dry bone study.

Introduction

The atlas vertebra (C1) constitutes the first cervical vertebra and serves a fundamental biomechanical role in supporting the cranium and transmitting its load to the axial skeleton [1,2]. Unlike typical cervical vertebrae, the atlas exhibits distinctive morphological characteristics and directly bears the weight of the skull, thereby classifying it as an atypical vertebra. The term “atlas” is derived from Greek mythology, symbolizing its function of bearing the cranial load.

Superiorly, the atlas articulates with the occipital condyles of the skull to form the atlanto-occipital joint, which permits flexion and extension movements of the head. Inferiorly, it articulates with the second cervical vertebra, the axis (C2), forming the atlanto-axial joint that enables axial rotation of the head and neck [2,3]. Both the atlas (C1) and axis (C2) are considered atypical vertebrae and demonstrate complex anatomical relationships with adjacent neurovascular structures, particularly the vertebral artery.

The third segment of the vertebral artery ascends in close proximity to the superior and lateral surfaces of the atlas vertebra on either side. This intimate anatomical relationship renders the artery vulnerable during surgical interventions involving the craniovertebral junction, including lateral mass screw fixation, transarticular screw placement for atlanto-axial stabilization, and lateral approaches to the foramen magnum. Injury to the vertebral artery during such procedures may result in severe intraoperative haemorrhage and compromised cerebral perfusion, potentially leading to neurological deficits [4]. Consequently, a thorough three-dimensional understanding of the morphometry and anatomy of the atlas vertebra and its surrounding neurovascular structures is essential for minimizing surgical complications and ensuring safe operative outcomes in the craniovertebral region.

Materials & Methods

The present descriptive statistical study was conducted in the Department of Anatomy. This study will be conducted at the Department of Anatomy, Index Medical College, Hospital & Research Centre, Indore, M.P.

Inclusion Criteria: Intact bones without any deformity were included in the study.

Exclusion Criteria: Broken bones and bones showing variations or deformities were excluded from the study.

The following Parameters were Included

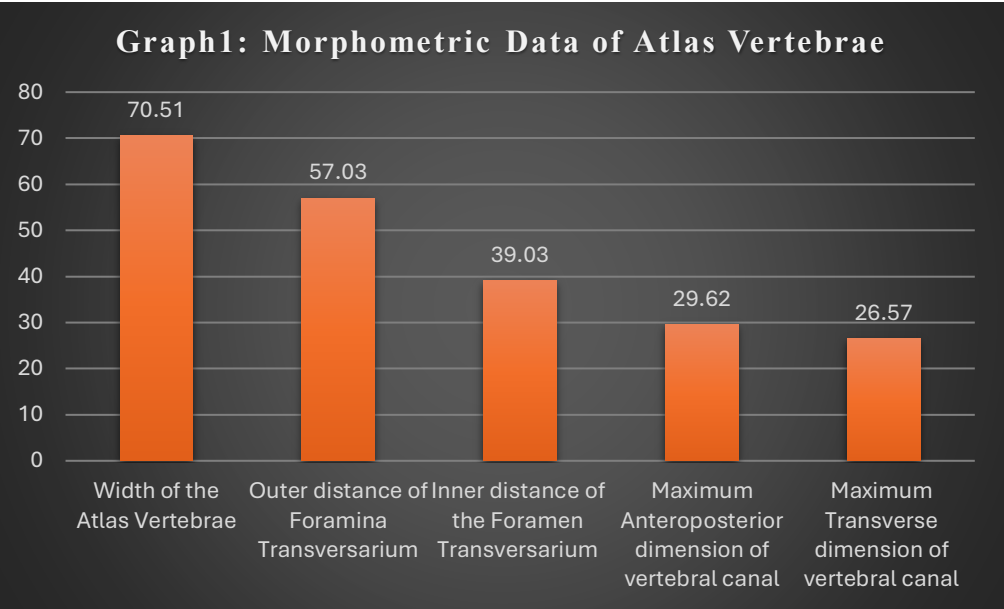
1. The linear distance measured between the outermost tips of the transverse processes of the atlas vertebra.
2. The transverse distance between the lateral borders of the right and left transverse foramina.
3. The distance between the medial margins of the bilateral foramina transversaria.
4. The maximum anteroposterior dimension of the vertebral foramen of the atlas.
5. The anteroposterior diameter of the superior articular facet of the atlas vertebra.
6. The transverse diameter of the superior articular facet of the atlas vertebra.

Statistical Analysis

The collected data will be analysed using IBM SPSS Statistics (version 16). Descriptive statistical measures, including mean, standard deviation, range, frequencies, and proportions, will be computed to summarize the data. Inferential statistical tests, such as the chi-square test and correlation analysis, will be applied to examine associations between the selected variables. A p value of less than 0.05 will be considered indicative of statistical significance.

Results

The atlas vertebra had a mean transverse width of **70.51 ± 8.12 mm**. The average distance between the lateral margins of the foramina transversaria was **57.03 ± 4.75 mm**, while the distance between their medial margins was **39.03 ± 8.76 mm**. The vertebral canal showed a mean anteroposterior diameter of **29.62 ± 2.03 mm** and a mean transverse diameter of **26.57 ± 3.82 mm**, indicating normal anatomical variation in the adult atlas vertebra. (Graph 1)



The mean outer

distance of the vertebral artery groove was **greater on the right side** (24.78 ± 3.38 mm) than on the left (22.18 ± 5.21 mm), and this difference was **statistically significant** ($p < 0.001$). In contrast, the mean inner distance showed **no significant side-to-side difference**, measuring 13.18 ± 1.78 mm on the right and 13.08 ± 2.12 mm on the left ($p = 0.66$). (Table 1)

Table 1: The range, mean value and standard deviation of the morphometric parameters of the vertebral artery groove (VAG) in human atlas vertebrae.			
Description of Parameter	Range (Min -Max) in mm	Mean±SD (mm)	P-value
Outer distance of the Right vertebral artery groove (VAG)	19.03-32.53	24.78±3.38	<0.0001
Outer distance of the Left vertebral artery groove	11.76-32.59	22.18±5.21	
Inner distance of Rt. Vertebral artery groove	9.63-16.73	13.18±1.78	0.66
Inner distance of the left vertebral artery groove (VAG)	8.85-17.31	13.08±2.12	

In a study of 150 dry adult human atlas vertebrae, the frequency of incomplete retroarticular canals was assessed. Incomplete canals were found in 12 vertebrae on the right side (8%) and the same frequency on the left side. Bilateral incomplete canals were present in 7 specimens (4.66%). Complete canals were rarer, with 6 on the right (4%) and 2 on the left (1.33%). No specimens showed bilateral complete canals or ponticuli postici. (Table 2)

Table 2- Frequency distribution of complete/incomplete retroarticular canal/ ponticulus posticus.

RETROARTICULAR CANAL/PONTICULUS POSTICUS
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	Incomplete (17)			Complete (6)		
	Right	Left	B/L	Right	Left	B/L
	12(8%)	12(8%)	7(4.66%)	6(4%)	2(1.33%)	0
Total	24(12%)			8(5.333%)		

The shapes of the superior articular facets were analysed in 150 dry adult human atlas vertebrae (300 facets total). The most common shape was oval, found in 43 right-sided (28.7%) and 44 left-sided (29.3%) facets, totalling 87 (29%). Kidney-shaped facets were the second most frequent, identified in 27 right (18%) and 36 left (24%) facets, for a total of 63 (21%).

Bilobed facets appeared in 21 right (14%) and 19 left-sided facets (12.7%), totalling 40 (13.33%). The figure-of-eight shape occurred in 14 right-sided (9.33%) and 12 left-sided (8%) facets, totalling 26 (8.7%). Rectangular shapes were found in 15 right-sided (10%) and 11 left-sided (7.33%) facets, for a total of 26 (8.7%).

Less common were leaf-shaped (17 facets), comma-shaped (13 facets), and trilobed facets (10 facets). Irregular and triangular shapes were the least frequent, each found in 9 facets (3%). (Table 3)

Table 3: Frequency distribution of superior articular facet morphology in dry adult human atlas vertebrae

Shape of SAF	Right Side (150)	Left Side (150)	Total (300)
OVAL	43(28.7%)	44(29.3%)	87(29%)
KIDNEY	27(18%)	36(24%)	63(21%)
BILOBED	21(14%)	19(12.7%)	40(13.33%)
FIGURE 8	14(9.33%)	12(8%)	26(8.7%)
RECTANGULAR	15(10%)	11(7.33%)	26(8.7%)
LEAF	8(5.33%)	9(6%)	17(5.7%)
COMMA	7(4.7%)	6(4%)	13(4.33%)
TRILOBED	5(3.33%)	5(3.33%)	10(3.33%)
IRREGULAR	5(3.33%)	4(2.7%)	9(3%)
TRIANGULAR	5(3.33%)	4(2.7%)	9(3%)



Figure 2 - Shows Incomplete Retroarticular Canal.



Figure 3 - Shows Complete Retroarticular Canal.

DISCUSSION

In the present study, the **mean transverse width of the atlas vertebra** was **70.51 ± 8.12 mm**. This observation is in close agreement with the findings of **Sengul and Kadioglu** [4], who reported a mean atlas width of approximately **72 mm** in their morphometric study of dry cervical vertebrae. Similarly, **Gupta et al.** [5] and **Patil et al.** [6] reported mean values of **69-74 mm**, indicating a relatively consistent transverse dimension across different Indian populations.

CT-based morphometric analyses by **Zhang et al.** [7] and **Li et al.** [8] also reported atlas width values comparable to the present study, suggesting that osteological and radiological measurements are broadly concordant. Minor variations between studies may be attributed to differences in population demographics, sex distribution, and methodology (dry bone versus imaging-based analysis).

The present study recorded a **mean outer distance of the foramina transversaria** of **57.03 ± 4.75 mm** and a **mean inner distance** of **39.03 ± 8.76 mm**. These values closely correspond with observations by **Tubbs et al.** [9] and **Cattrysse et al.** [10], who emphasised significant inter-individual variability in transverse foraminal dimensions.

CT-based evaluations by **Yilmaz et al.** [11] further corroborated wide dimensional variability of the foramina transversaria, underscoring the clinical importance of individualised preoperative assessment during C1 lateral mass screw placement and posterior cervical instrumentation.

In the present study, the **mean anteroposterior diameter of the vertebral canal** measured **29.62 ± 2.03 mm**, while the **mean transverse diameter** was **26.57 ± 3.82 mm**. These findings are consistent with earlier reports by **Bozbuga et al.** [12] and **Naderi et al.** [13], who noted that the atlas vertebra possesses a relatively wider vertebral canal compared to subaxial cervical vertebrae.

Similarly, **Hasan et al.** [14] and **Li et al.** [8] reported comparable canal dimensions, reinforcing the concept that the atlas provides generous space for the spinal cord under normal anatomical conditions. Reduced canal dimensions described in other studies have been associated with congenital anomalies and atlantoaxial instability rather than normal variation.

The **outer distance of the vertebral artery groove** in the present study was significantly greater on the **right side** (**24.78 ± 3.38 mm**) compared to the **left side** (**22.18 ± 5.21 mm**), with statistical significance ($p < 0.001$). A similar right-sided dominance was reported by **Karaikovic et al.** [15] and **Sethi et al.** [16], who attributed this asymmetry to functional dominance of the right vertebral artery.

Angiographic studies by **Hong et al.** [17] have demonstrated right vertebral artery dominance in a substantial proportion of individuals, offering a plausible anatomical explanation for the asymmetry observed in bony groove dimensions. In contrast, the **inner distance of the vertebral artery groove** showed no statistically significant side difference in the present study, a finding that aligns with observations by **Jayanthi and Kulkarni** [18].

In the present study, **incomplete retroarticular canals** were more frequently observed than complete forms, with unilateral incomplete canals present in **8%** on both sides and

bilateral incomplete canals in **4.66%** of specimens. **Complete retroarticular canals** were comparatively rare and were not observed bilaterally.

These findings are consistent with reports by **Tubbs et al.** [9], **Kim et al.** [19], and **Bayrakdar et al.** [40], all of whom documented a higher prevalence of incomplete ponticulus posticus. The low incidence of bilateral complete ponticulus posticus observed in the present study mirrors global data, which consider bilateral complete forms uncommon.

Morphometric studies by **Karau Bundi et al.** [18] demonstrated reduced cross-sectional area within complete bony bridges when compared to the transverse foramen, suggesting a potential risk of vertebral artery compression. This anatomical consideration reinforces the clinical relevance of identifying ponticuli prior to posterior C1 instrumentation.

The present study demonstrated that **oval-shaped superior articular facets** were the most common morphology (29%), followed by **kidney-shaped facets** (21%). These findings closely align with those of **Gupta et al.** [5], **Kumar and Nagar** [20], and **Al-Hadidi et al.** [21], all of whom reported oval and kidney shapes as the predominant configurations.

Less common morphologies such as bilobed, figure-of-eight, trilobed, and irregular facets have also been documented in previous studies and are considered developmental variations rather than pathological abnormalities. The diversity of facet morphology observed across populations highlights the need for careful evaluation during atlanto-occipital fixation procedures, where facet shape may influence joint congruency and screw placement.

Conclusion

In conclusion, the findings of this study align closely with both national and international literature, while also revealing notable population-specific variations and side dominance in key morphometric parameters. The observed asymmetry of the vertebral artery groove, along with the diversity in particular facet morphology, underscores the necessity for individualised anatomical assessments, especially in surgical planning at the craniovertebral junction.

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