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MORPHOMETRIC ANALYSIS OF THE HUMAN ATLAS VERTEBRA: AN OSTEOLOGICAL STUDY

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Abstract
The atlas vertebra (C1) plays a critical role at the craniovertebral junction by supporting the skull and facilitating complex head movements. Owing to its atypical structure and close association with vital neurovascular elements, particularly the vertebral artery, detailed morphometric knowledge of the atlas is essential for safe surgical and radiological practice.
The present descriptive study analysed **150 dry adult human atlas vertebrae** from the Indian population to document morphometric parameters and morphological variations. Measurements included atlas width, transverse foraminal distances, vertebral canal dimensions, vertebral artery groove morphometry, and articular facet morphology, following
Established osteometric protocols. The study demonstrated measurable variability and significant side-to-side asymmetry in several parameters, especially those related to the vertebral artery groove and articular facets. These findings provide population-specific reference data and emphasise the importance of individualised anatomical assessment during craniovertebral junction procedures.

Keywords: Atlas vertebra; C1 morphometry; vertebral artery groove; ponticulus posticus; craniovertebral junction

Introduction

The vertebral column forms the central skeletal axis of the human body, providing structural support, protection to the spinal cord, and attachment for muscles and ligaments [1,2]. The cervical region is distinguished by high mobility and complex biomechanics, particularly at the craniovertebral junction (CVJ) [3,4].
Among the cervical vertebrae, the atlas (C1) is anatomically unique, lacking a vertebral body and spinous process, and forming a ring-like structure that supports the skull [1,5]. Superiorly, it articulates with the occipital condyles at the atlanto-occipital joints, allowing flexion and extension, while inferior articulation with the axis (C2) enables rotation of the head [2,4].
The vertebral artery ascends along the superior surface of the posterior arch of the atlas, rendering this region particularly vulnerable during surgical procedures such as posterior fixation and lateral mass screw placement [6,7]. Anatomical variations of the atlas—including ponticulus posticus, altered transverse foramina, and articular facet asymmetry—have been shown to increase the risk of vertebral artery injury and neurovascular compromise [8–10].

Therefore, detailed morphometric evaluation of the atlas vertebra is essential for anatomists, surgeons, and radiologists involved in CVJ assessment and intervention [4,6].

Materials and Methods

A descriptive osteological study was conducted in the **Department of Anatomy, Index Medical College, Hospital & Research Centre, Indore**, after obtaining Institutional Ethics Committee approval. A total of **150 dry adult human atlas vertebrae** were examined over a two-year period (2023–2025).

Only intact vertebrae without deformity were included, as recommended in standard osteological studies. Measurements were recorded using a digital Vernier caliper (accuracy 0.01 mm), a double-tip compass, and a transparent scale. Each parameter was measured repeatedly by the same observer to minimise intra-observer error. Morphological variations were documented photographically.

Statistical analysis was performed using **IBM SPSS Statistics (version 29)**, with $p < 0.05$ considered statistically significant.

Results

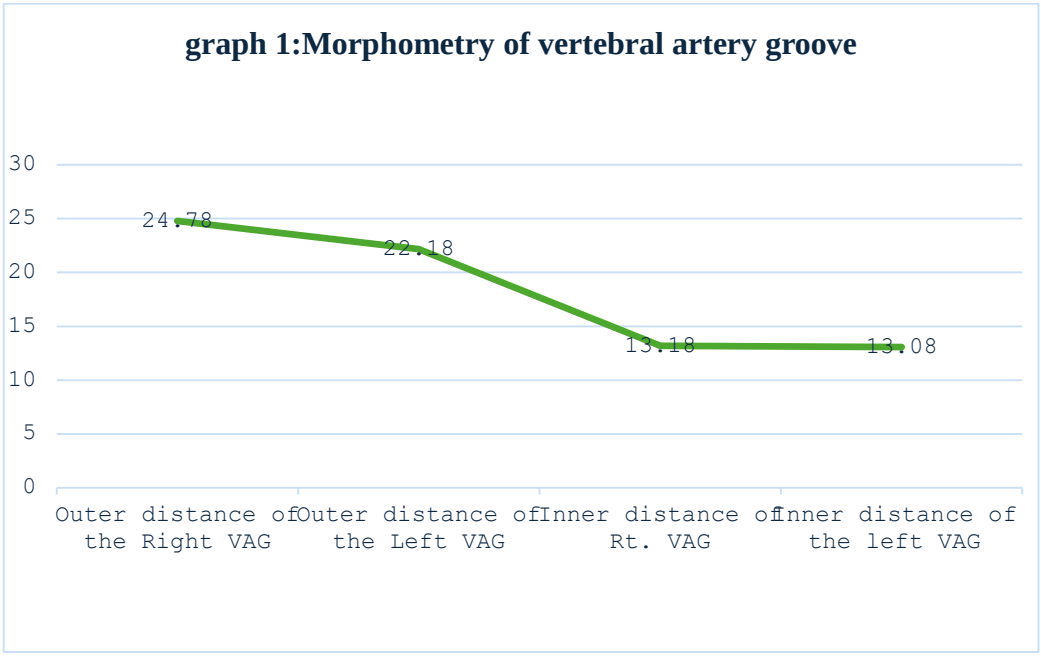
The mean transverse width of the atlas vertebra was **70.51 ± 8.12 mm**, comparable to values reported in previous osteological and radiological studies [33–35]. The mean outer and inner distances between the foramina transversaria measured **57.03 ± 4.75 mm** and **39.03 ± 8.76 mm**, respectively, reflecting normal inter-individual variability. The vertebral canal demonstrated a mean anteroposterior diameter of **29.62 ± 2.03 mm** and a transverse diameter of **26.57 ± 3.82 mm**, consistent with prior morphometric observations. (Table 1)

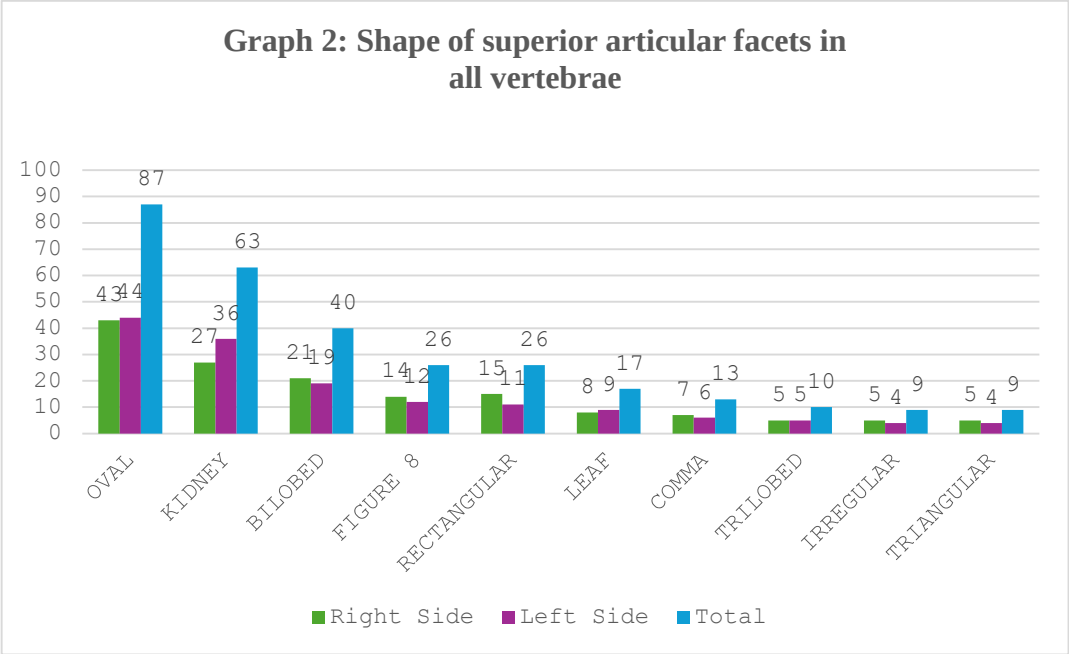
The vertebral artery groove showed significant asymmetry. The mean outer distance was greater on the right side (**24.78 ± 3.38 mm**) than on the left (**22.18 ± 5.21 mm; p < 0.001**), while the inner distance showed no significant side difference. Incomplete ponticulus posticus was more common than complete forms, and no bilateral complete ponticulus posticus was observed, in agreement with global prevalence patterns. (Graph 1)

Oval-shaped superior articular facets were the most frequent morphology, followed by kidney-shaped and bilobed forms, as described by earlier authors. Both superior and inferior articular facets demonstrated statistically significant side-to-side differences in morphometric parameters. (Graph 2)

Table 1: The range, mean, and SD of the morphometric parameters in adult human atlas vertebrae

Description of Parameter	Range (Min-Max) in mm	Mean± SD (mm)
Width of the Atlas Vertebrae	54.27 – 86.753	70.51±8.12 mm
Outer distance of Foramina Transversarium	47.53 – 66.52	57.03±4.75 mm
Inner distance of the Foramen Transversarium	21.52 – 56.54	39.03±8.76 mm
Maximum Anteroposterior dimension of the vertebral canal	25.57 – 33.67	29.62±2.03 mm
Maximum Transverse dimension of the vertebral canal	18.92 – 34.21	26.57±3.82 mm





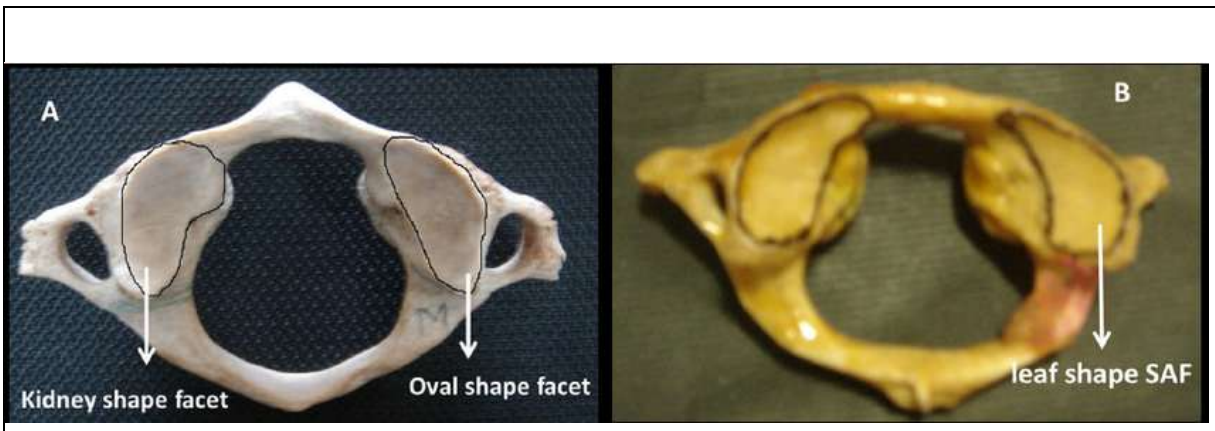


Fig 1: A) Showing kidney and oval shape superior articular facet (SAF) B) Showing leaf shape superior articular facet (SAF).

Discussion

In the present study, the mean transverse width of the atlas vertebra was 70.51 ± 8.12 mm. This value is closely comparable with the findings of **Sengul and Kadioglu** [11], who reported a mean atlas width of approximately 72 mm in dry bone specimens. Similar ranges have been documented in Indian populations by **Gupta et al**. [12] and **Yogesh et al**. [13], who observed values between 69 mm and 74 mm. Radiological studies by **Zhang et al.** [35] further support these observations, indicating that atlas width remains relatively consistent across populations, with minor variations attributable to ethnicity, sex distribution, and measurement methodology.

The mean outer (57.03 ± 4.75 mm) and inner (39.03 ± 8.76 mm) distances between the foramina transversaria recorded in the present study align well with those reported by **Tubbs et al.** [15] and **Cattrysse et al.** [16]. Both authors emphasised substantial inter-individual variability in transverse foraminal dimensions. CT-based morphometric analysis by **Yilmaz et al.** [17] similarly demonstrated wide variation, underscoring the surgical relevance of individualised assessment during C1 lateral mass screw placement and posterior cervical instrumentation.

The vertebral canal dimensions observed in the present study—anteroposterior diameter of 29.62 ± 2.03 mm and transverse diameter of 26.57 ± 3.82 mm—are consistent with findings reported by **Bozbuga et al.** [18] and **Naderi et al.** [19]. Comparable measurements were also noted in CT-based studies by **Li et al.** [20]. These findings confirm that the atlas vertebra typically possesses a relatively wide vertebral canal compared to subaxial cervical vertebrae, providing adequate space for the spinal cord under normal anatomical conditions.

A significant observation in the present study was the right-sided predominance of the outer distance of the vertebral artery groove ($p < 0.001$). Similar right-sided dominance has been reported by **Karaikovic et al**. [21] and **Sethi et al**. [22]. Angiographic studies by **Hong et al.** [23] demonstrated right vertebral artery dominance in a large proportion of individuals, providing a plausible anatomical basis for this bony asymmetry.

Incomplete ponticulus posticus was more frequent than complete forms in the present study, and no bilateral complete ponticulus posticus was observed. This pattern corresponds closely with reports by **Tubbs et al**. [24], **Kim et al**. [25], and **Bayrakdar et al**. [26], all of whom documented a higher prevalence of incomplete bony bridges. The clinical importance of this finding is supported by **Karau Bundi et al**. [27], who demonstrated reduced cross-sectional area within complete ponticuli compared with the transverse foramen, potentially predisposing to vertebral artery compression.

The predominance of oval-shaped superior articular facets, followed by kidney-shaped and bilobed forms, observed in the present study is consistent with findings reported by **Gupta et al.** [28], **Kumar and Nagar** [5], and **Al-Hadidi et al** [6]. These authors similarly identified oval and kidney shapes as the most common configurations across different populations.

Additionally, the statistically significant side-to-side differences in both superior and inferior articular facet dimensions observed in the present study parallel findings reported by Sengul and Kadioglu [11] and **Sharma et al.** [7]. Such asymmetry has been attributed to functional dominance, habitual posture, and differential biomechanical loading at the craniovertebral junction.

Conclusion

The atlas vertebra demonstrates significant morphometric and morphological variability while preserving its essential anatomical characteristics. The observed side-to-side asymmetry in the dimensions of the vertebral artery grooves and articular facets carries important clinical implications. The population-specific reference data generated by this study enhance surgical planning, improve radiological interpretation, and deepen anatomical understanding of the craniovertebral junction.

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