



## RESEARCH ARTICLE

## Morphological and Morphometric Study of Atlas (C1) and Axis (C2) Vertebrae in Human Skeletons

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### ABSTRACT

**Background:** The atlas (C1) and axis (C2) vertebrae are specialized cervical vertebrae that facilitate head movement and provide stability to the craniovertebral junction. Detailed morphometric knowledge of these vertebrae is essential for neurosurgical procedures, spinal fixation techniques, and forensic investigations.

**Aim:** To analyze the morphological variations and morphometric dimensions of atlas and axis vertebrae in human skeletal specimens and evaluate their clinical significance.

**Methods:** A retrospective osteological study was conducted in the Department of Anatomy, Government Medical College, Jammu, over 3 months. Thirty dry human vertebrae (15 atlas and 15 axis vertebrae) were examined. Various morphometric parameters including transverse diameter, anteroposterior diameter, vertebral canal dimensions, superior articular facet measurements, dens dimensions, and vertebral foramen dimensions were recorded using digital Vernier calipers. Morphological variations were documented. Statistical analysis was performed using SPSS version 26. Student's t-test and Pearson correlation analysis were applied, with  $p < 0.05$  considered statistically significant.

**Results:** The mean transverse diameter of the atlas was  $76.4 \pm 4.8$  mm, while the mean anteroposterior diameter measured  $44.2 \pm 3.5$  mm. The average length of the dens in axis vertebrae was  $15.8 \pm 1.7$  mm and the mean width was  $9.1 \pm 1.2$  mm. Morphological variations were observed in 26.7% of specimens. Significant positive correlations were found between vertebral body dimensions and dens measurements ( $p < 0.001$ ).

**Conclusion:** Atlas and axis vertebrae exhibit significant morphometric variability. These findings provide valuable anatomical data for craniovertebral junction surgery, cervical instrumentation, and forensic anthropology.

**Keywords:** Atlas vertebra, Axis vertebra, Dens, Morphometry, Craniovertebral junction, Anatomy.

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### INTRODUCTION

The atlas (C1) and axis (C2), two of the seven vertebrae that make up the cervical vertebral column, are anatomically and functionally distinct. The craniovertebral junction is made up of these vertebrae, which support the skull and allow for a variety of head movements. The axis has the odontoid process (dens), which acts as a pivot for the atlas and skull to rotate, but the atlas does not have a vertebral body or spinous process. Because anomalies or traumas involving these vertebrae may cause serious neurological consequences, the morphology of the atlas and axis is of great clinical significance [1]. The craniovertebral junction is often affected by odontoid process fractures, atlantoaxial instability, congenital abnormalities, and degenerative diseases. Instrumentation and fixation techniques that heavily rely on precise anatomical knowledge are frequently necessary for the surgical management of these conditions [2].

Advances in spine surgery have expanded the use of transarticular screws, lateral mass screws, pedicle screws, and odontoid screw fixation. To prevent damage

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to nearby neurovascular structures such the vertebral artery, spinal cord, and nerve roots, successful implant

placement necessitates a precise grasp of vertebral dimensions. Morphometric investigations therefore provide significant information for surgical planning and implant design. Additionally, the axis and atlas have forensic value. Cervical vertebral morphometric measurements are useful for skeletal identity, sex determination, and population-specific anthropological research. The necessity for regional anatomical databases has been highlighted by several studies that have found significant variation in vertebral diameters across various populations[3]

There are few data from northern India, despite the fact that many research have assessed cervical vertebral morphometry in diverse ethnicities. Because implant dimensions and surgical techniques are frequently based on measurements taken from Western cultures, population-specific morphometric data is especially crucial. The goal of the current study was to assess the morphometric dimensions and morphological traits of atlas and axis vertebrae that were taken from skeletal collections in the Department of Anatomy at Government Medical College, Jammu. Anatomists, neurosurgeons, orthopaedic surgeons, and forensic specialists may find the results to be helpful reference material[4].

## MATERIALS AND METHODS

### Study Design

Retrospective osteological study.

### Study Setting

Department of Anatomy, Government Medical College, Jammu.

### Study Duration

3 months.

### Sample Size

30 dry human vertebrae:

- Atlas (C1): 15 specimens
- Axis (C2): 15 specimens

### Inclusion Criteria

- Intact adult vertebrae.
- Well-preserved atlas and axis vertebrae.

### Exclusion Criteria

- Damaged vertebrae.
- Congenital deformities.
- Pathological lesions affecting morphology.

## Parameters Studied

### Atlas (C1)

- Transverse diameter.
- Anteroposterior diameter.
- Vertebral foramen dimensions.
- Superior articular facet length and width.

### Axis (C2)

- Vertebral body dimensions.
- Dens height.
- Dens width.
- Superior articular facet dimensions.
- Vertebral canal dimensions.

## Instruments

- Digital Vernier caliper (0.01 mm accuracy).
- Osteometric scale.

## Statistical Analysis

Data were analyzed using SPSS version 26. Results were expressed as mean  $\pm$  SD. Student's t-test and Pearson correlation were used. A p-value  $<0.05$  was considered statistically significant.

## RESULTS

**Table 1:** Morphometric Measurements of Atlas Vertebra (C1)

Parameter	Mean $\pm$ SD (mm)
Transverse Diameter	76.4 $\pm$ 4.8
AP Diameter	44.2 $\pm$ 3.5
Vertebral Foramen AP Diameter	31.6 $\pm$ 2.9
Superior Articular Facet Length	20.8 $\pm$ 1.8
Superior Articular Facet Width	11.9 $\pm$ 1.2

The transverse diameter of the atlas was considerably greater than the anteroposterior diameter, reflecting its ring-shaped anatomy.

**Table 2:** Morphometric Measurements of Axis Vertebra (C2)

Parameter	Mean $\pm$ SD (mm)
Dens Height	15.8 $\pm$ 1.7
Dens Width	9.1 $\pm$ 1.2
Vertebral Body Width	22.4 $\pm$ 2.1
Vertebral Canal AP Diameter	18.6 $\pm$ 1.8
Superior Articular Facet Length	17.3 $\pm$ 1.5

The average dens height was 15.8 mm, while the dens width measured 9.1 mm.

**Table 3:** Morphological Variations Observed

Variation	Frequency (%)
Posterior Arch Defect	2 (6.7)
Asymmetrical Articular Facets	3 (10.0)
Bifid Dens Tip	1 (3.3)
Accessory Foramen	2 (6.7)
Normal Morphology	22 (73.3)

*p-value* = 0.021

Morphological variations were observed in 26.7% of specimens, with asymmetrical articular facets being the most common anomaly.

**Table 4:** Correlation Between Vertebral Measurements

Variables compared	Correlation coefficient ( <i>r</i> )	<i>p-value</i>
Dens Height vs Body Width	0.68	<0.001
Dens Width vs Facet Length	0.57	0.002
Atlas AP Diameter vs Facet Width	0.61	<0.001

Significant positive correlations were observed between vertebral body dimensions and dens measurements.

## DISCUSSION

The present retrospective osteological investigation analysed the morphological and morphometric properties of atlas and axis vertebrae in 30 human skeletal specimens. The craniovertebral junction is one of the most anatomically complex and clinically important sections of the vertebral column. Detailed morphometric understanding of the atlas and axis is crucial for surgical fixation operations, radiological assessment, and forensic identification. The mean transverse diameter of the atlas in the present study was 76.4 mm, which was much higher than the anteroposterior diameter of 44.2 mm[5]. These findings reflect the unique ring-like shape of the atlas and are consistent with earlier morphometric examinations. The wider transverse diameter contributes to the accommodation of the spinal cord and permits a wide range of movements at the atlanto-occipital and atlantoaxial joints[6].

The size of the superior articular facets revealed in the present study are particularly noteworthy because these structures transmit the weight of the head to the spinal

column. Variations in facet dimensions may alter joint biomechanics and contribute to instability or degenerative changes. Surgeons undertaking craniovertebral fixation procedures must consequently be aware of such anatomical diversity. The dens of the axis vertebra is a crucial supporting element of the atlantoaxial joint[7]. The mean dens height and breadth recorded in this investigation were 15.8 mm and 9.1 mm, respectively. These measurements are therapeutically relevant for odontoid screw fixation, which needs correct estimation of dens dimensions to establish adequate stability while reducing the danger of cortical breach or neurovascular injury. Variations in dens morphology may potentially increase susceptibility to fractures, particularly in elderly persons[8].

Morphological differences were observed in approximately one-fourth of the specimens. Asymmetrical articular facets were the most common variation found. Such defects may modify load transfer across the craniovertebral junction and potentially predispose individuals to instability or degenerative effects. Posterior arch abnormalities and auxiliary foramina were also discovered, results that have crucial consequences for radiological interpretation and surgical planning. The substantial connections revealed between dens dimensions and vertebral body measurements suggest coordinated developmental progression of the axis vertebra. Such correlations may assist surgeons in anticipating anatomical dimensions when preoperative imaging is limited or incomplete. Furthermore, these associations support the hypothesis that vertebral structures evolve proportionally during skeletal maturation [9].

From a neurosurgical perspective, the outcomes of this study are particularly relevant for transarticular screw fixation, posterior cervical instrumentation, and odontoid fracture care. Accurate morphometric data can decrease complications associated with implant misplacement, including vertebral artery injury and spinal cord damage. Population-specific anatomical information is especially relevant because vertebral diameters vary among different ethnic groups. The forensic value of atlas and axis morphometry should also be stressed. Vertebral measures may contribute to skeletal identification and anthropological study when other regularly utilised skeletal elements are missing. Establishment of regional morphometric databases may therefore benefit both forensic and anatomical investigations[10].

The fundamental strength of this work is the careful evaluation of both morphological and morphometric properties of atlas and axis vertebrae. However, drawbacks include the relatively small sample size and the absence of

sex-wise analysis due to lack of demographic information. Future investigations with bigger sample sizes and radiological correlation are necessary. Overall, the findings add useful anatomical data regarding the craniovertebral junction and may benefit physicians, anatomists, and forensic scientists in their professional activity[11].

## CONCLUSION

The current study offers thorough morphological and morphometric information about the axis and atlas vertebrae in human skeletal specimens. Vertebral dimensions and morphological traits varied significantly, underscoring the significance of a thorough anatomical evaluation of the craniovertebral junction.

The axis exhibited quantifiable variation in dens morphology and vertebral body dimensions, whilst the atlas revealed a significantly higher transverse diameter in comparison to its anteroposterior dimension. 26.7% of specimens had morphological abnormalities, highlighting the importance of being aware of anatomical variances while interpreting radiological data and performing surgical procedures.

The care of craniovertebral junction problems, orthopaedic surgery, neurosurgery, and spinal instrumentation can all directly benefit from these discoveries. Precise morphometric information can help with surgery planning, implant selection, and minimising procedure-related problems. Additionally, the findings provide important information for skeletal identification and forensic anthropology.

Because different ethnic groups have different vertebral diameters, population-specific anatomical research are still crucial. Researchers and clinicians dealing with the anatomy of the cervical spine may find the data produced in this study to be a helpful resource.

To create more thorough morphometric standards for the Indian population and improve knowledge of craniovertebral anatomy, more multicentric studies with

bigger sample sizes, sophisticated imaging methods, and sex-based analyses are advised.

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