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Morphometric evaluation of the body and odontoid process of the axis vertebra and its clinical significance. A cross-sectional anatomical study.

Dr. Adabala N. V. V. Veerraju
Professor, Department of Anatomy, Konaseema Institute of Medical Sciences and Research Foundation, Amalapuram, Andhra Pradesh, India

Abstract:
Introduction:
The axis, which is the second cervical vertebra, serves as a pivot, allowing the atlas to rotate and support the head. Despite its small size, this area can lead to significant complications because of the intricate anatomy of the cranio-cervical junction. The axis vertebra is distinct because it features a dens or odontoid process. Fractures of the dens in the axis account for 7–27% of all cervical spine fractures. Surgical procedures in the craniovertebral region carry a high risk, as vertebral artery injury is common. Therefore, a comprehensive understanding of the anatomy of the body and the odontoid process of the axis vertebra is essential.

Materials and methods:
A cross-sectional study was carried out using fifty-two intact dry human axis vertebrae of unspecified sex. Measurements of the body and odontoid process of these vertebrae were obtained with a digital vernier caliper, which has an accuracy of up to 0.01mm. Statistical analysis was performed using IBM SPSS Version 21.

Results:
The body of the axis vertebra measured as follows: mean length of the body, 14.93±1.11 mm; vertebral body superior width, 15.79±1.76 mm; vertebral body inferior width, 16.22±1.31 mm; vertebral body anterior height, 18.69±2.17 mm; and vertebral body posterior height, 15.96±1.89 mm. The odontoid process of the axis vertebra measured as follows: odontoid process height, 17.60±1.94 mm; odontoid process anteroposterior diameter, 10.61±0.85 mm; maximum transverse diameter of the odontoid process, 9.78±0.93 mm; minimum transverse diameter of the odontoid process, 8.53±0.82 mm; atlanto-odontoid facet height, 9.67±1.43 mm; and atlanto-odontoid facet width, 7.86±0.90.

Conclusion:
These measurements are essential for the safe and effective application of modern orthopedic techniques. This data helps surgeons in reducing complications such as vertebral artery injury and other vital structures during surgical procedures in the cranio-vertebral region.

Recommendations:
Future studies should include larger, diverse samples with radiologic correlation.

Key words: *Atlanto-Odontoid facet, Axis vertebrae, Morphometry, Odontoid process, Vernier caliper, Vertebral artery.*
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Corresponding Author: *Dr. Adabala N. V. V. Veerraju*
Email: ***adabalaveerraju23@gmail.com***
Professor, Department of Anatomy, Konaseema Institute of Medical Sciences and Research Foundation, Amalapuram, Andhra Pradesh, India

Introduction

The axis, the second cervical vertebra, plays a pivotal role in permitting wide rotational movements at the atlanto-axial joint (1). It articulates with the atlas through a pivot mechanism that allows the head to turn smoothly from side to side (2). The odontoid process, or dens, forms the central

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peg of this articulation, a conical, tooth-like projection approximately 1.5–2 cm long that arises from the superior surface of the axis body (3, 4). Embryologically, the dens represents the centrum of the atlas and consists of a broad upper segment (head) and a narrower constricted part (neck) (2). Its anterior surface bears an oval facet that articulates with the anterior arch of the atlas to constitute the median atlanto-axial joint. Detailed morphometric knowledge of this structure is indispensable for interpreting cranio-cervical pathologies and for planning operative procedures (5).

The body of the axis extends inferiorly and anteriorly, overlapping the upper surface of the third cervical vertebra (4). Its inferior aspect is typically convex transversely and concave anteroposteriorly (3). Increasing clinical reliance on screw-based fixation for odontoid fractures, which constitute about 7–20 % of all cervical spine fractures, has intensified the importance of precise anatomical characterization (6, 7). Anderson and D'Alonzo classified these fractures into three types, with type II and type III being most prevalent (8).

Despite its advantages, trans-pedicular or odontoid screw fixation in this region poses a high risk to adjacent neurovascular structures, including the vertebral artery, spinal cord, and cervical nerve roots (9). The vertebral artery's proximity to the axis varies considerably, coursing either along its undersurface or near the foramen transversarium, making anatomical familiarity vital to prevent iatrogenic injury during lateral or posterolateral approaches to the cranio-cervical junction (10).

Beyond trauma, numerous non-traumatic disorders such as infections, neoplasms, degenerative or inflammatory conditions, vascular anomalies, and congenital malformations can compromise this complex region (11). Surgical procedures, including anterior cranio-vertebral stabilization, transoral odontoidectomy, and odontoid screw fixation, therefore demand exact morphometric orientation for accurate plate and screw placement (12). Quantitative anatomical data further aid in designing appropriately sized implants and instrumentation.

Accordingly, the present study aimed to provide detailed morphometric measurements of the body and odontoid process of the axis vertebra to facilitate safer and more effective application of modern surgical techniques in the cranio-vertebral region.

Methodology

Study Design and Setting

An observational cross-sectional study was conducted in the Department of Anatomy at Konaseema Institute of Medical Sciences and Research Foundation (KIMS & RF), Amalapuram, located in Dr. B.R. Ambedkar Konaseema district, Andhra Pradesh, India. The institute is a recognized tertiary teaching hospital affiliated with Dr. NTR University of Health Sciences, Vijayawada, catering to both urban and rural populations of the Godavari delta region. The Department of Anatomy houses a well-equipped bone bank and dissection hall containing a rich collection of preserved skeletal specimens, providing ideal facilities for detailed morphometric and osteological research. The study was carried out over six months, from December 2024 to May 2025.

Sample Size and Selection Criteria

A total of fifty-two intact, dry human axis vertebrae of unspecified age and sex, obtained from the departmental bone bank, were included. Vertebrae with well-preserved morphology were selected, while those that were damaged or deformed were excluded from the study.

Parameters Observed

Morphometric analysis of the body and odontoid process of each vertebra was performed using a digital vernier caliper with a precision of 0.01 mm. The following measurements were recorded (Figures 1 and 2; Tables 1 and 2):

Vertebral body length (VBL): anteroposterior diameter across the base of the vertebral body.

Vertebral body superior width (VBSW): transverse diameter at the base of the superior surface.

Vertebral body inferior width (VBIW): transverse diameter at the base of the inferior surface.

Vertebral body anterior height (VBAH): vertical height from the superior to inferior border at the anterior midline.

Vertebral body posterior height (VBPH): vertical height from the superior to inferior border at the posterior midline.

Odontoid process height (OPH): measured from the superior border of the superior articular facet to the tip of the dens.

Odontoid process anteroposterior diameter (OPD): distance between the anterior and posterior surfaces.

Maximum transverse diameter of the odontoid process (OPW-Max).

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Minimum transverse diameter of the odontoid process (OPW-Min).
Atlanto-odontoid facet height (AOFH).
Atlanto-odontoid facet width (AOFW).

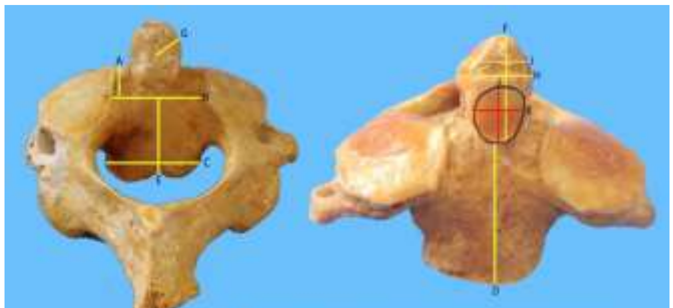
Figure 1 : Measurement of Various Parameters of Axis Vertebra

Morphological Observations

In addition to morphometric parameters, the following features were noted macroscopically:
Appearance of the odontoid process (lordotic, kyphotic, or straight).
Shape of the ventral facet (elliptical or oval).
Shape of the dorsal facet (elliptical or round).

Figure 2 : Morphology of Odontoid Process


Measures to Minimize Bias

To reduce observational bias, both authors independently performed the measurements. In cases of discrepancy, the specimens were re-examined jointly, and consensus was reached before final recording.

Data Analysis

All data were tabulated in Microsoft Excel and analyzed using IBM SPSS Version 21. Descriptive statistics, including mean and standard deviation, were calculated for each parameter. The results were presented in tabular form to facilitate interpretation.

Ethical Considerations

Ethical approval was obtained from the Institutional Ethics Committee of Konaseema Institute of Medical Sciences and Research Foundation, Amalapuram. All specimens were anonymized, maintaining confidentiality and ethical compliance.

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Results:

The results obtained from the examination of the body and odontoid process of 52 dry human axis vertebrae are recorded and listed in Tables 1 and 2.

Table 1: Range, mean, and standard deviation of various parameters of the body and odontoid process observed in the present study.

Parameter	Range		Mean	Standard Deviation
	Maximum	Minimum		
Vertebral body length	12.74	17.70	14.93	1.11
Vertebral body superior width	10.81	18.79	15.79	1.76
Vertebral body inferior width	14.81	20.01	16.22	1.31
Vertebral body anterior height	14.87	24.71	20.69	2.17
Vertebral body posterior height	11.20	20.92	16.96	1.89
Odontoid process height	12.80	20.95	17.60	1.94
Odontoid process anteroposterior diameter	8.78	12.43	10.61	0.85
Maximum transverse diameter of the odontoid process	8.56	11.42	9.78	0.93
Minimum transverse diameter of the odontoid process	6.29	10.96	8.53	0.82
Atlanto-odontoid facet height	7.43	12.58	9.67	1.43
Atlanto-odontoid facet width	6.10	9.29	7.86	0.90

Table 2: Morphological appearance of the odontoid process and shapes of the ventral and dorsal facets observed in the present study.

Morphological feature	Type	Number of specimens identified	Percentage
Macroscopic appearance of the odontoid process	Lordotic	35	67.3%
	Kyphotic	10	19.2%
	Straight	7	13.5%
Shape the ventral facet on the odontoid process.	Vertical elliptical	38	73.1%
	Oval	14	26.9%
Shape the dorsal facet on the odontoid process.	Horizontal elliptical	40	76.9%
	Round	12	23.1%

The measurements of various parameters of the body of the axis vertebra recorded in the present study were as follows: mean length of the body, 14.93±1.11 mm; vertebral body superior width, 15.79±1.76 mm; vertebral body inferior width, 16.22±1.31 mm; vertebral body anterior height, 20.69±2.17 mm; and vertebral body posterior height, 16.96±1.89 mm.

The measurements of various parameters of the odontoid process of the axis vertebra recorded in the present study were as follows: odontoid process height, 17.60±1.94 mm; odontoid process anteroposterior diameter, 10.61±0.85 mm; maximum transverse diameter of the odontoid process, 9.78±0.93 mm; minimum transverse diameter of the odontoid process, 8.53±0.82 mm; atlanto-odontoid facet

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height, 9.67±1.43 mm; and atlanto-odontoid facet width, 7.86±0.90.

Various morphological appearances of the odontoid process of the axis vertebrae were observed. Of the 52 vertebrae examined, 35 were lordotic, 10 were kyphotic, and 7 were straight. The shapes of the ventral and dorsal facets of the odontoid process of the axis vertebrae were observed. In 38 specimens, the ventral facet on the odontoid process was vertically elliptical, whereas in the remaining 14 specimens, it was oval. In 40 specimens, the dorsal facet on the odontoid process was horizontally elliptical, whereas in the remaining 12 specimens, it was round.

Discussion:

Various cervical spine procedures involve the body and odontoid process of the axis vertebra, including anterior atlanto-axial fixation, anterior odontoid screw fixation, and odontoidectomy [12]. In the present study, several morphometric parameters of the axis vertebra were measured, including vertebral body length, superior and inferior widths, and anterior and posterior heights. These measurements were compared with values reported in previous literature to highlight anatomical variation across populations. Such morphometric data are also valuable in forensic and anthropological research, as population-specific variations have been documented, including smaller axis vertebrae in certain native groups [17].

The mean vertebral body length observed in this study (14.93 mm) was similar to values reported in Indian populations [15,16] but slightly lower than those reported from studies conducted outside India [6,12,14]. The mean superior width (15.79 mm) was consistent with earlier Indian data but lower than the dimensions recorded elsewhere [6,13]. The inferior width (16.22 mm) exceeded several previous reports [13,14,16] but was slightly less than other international findings [12]. This parameter is particularly important when estimating the appropriate screw length for anterior plating of the axis vertebra.

The mean anterior height (20.69 mm) closely matched findings from Indian studies [15] but was marginally less than those documented in other populations [6,12,14]. When combined with the odontoid process height, the total axis height in this series was 38.29 mm, which aligns with previously reported values of 37.8 mm [18], 39.9 mm [19], and 38.7 mm [12]. These results suggest that a screw length of approximately 36 mm is generally optimal for anterior trans-odontoid fixation. The mean posterior height (16.96 mm) also corresponded well with previous Indian data [6,12,15,16] and was slightly lower than other reported measurements [13,14].

Atlanto-dental instability can occur due to hypertrophy of the odontoid process, which may result in neurological compression [19]. Formation of a pseudotumor around the dens can further aggravate instability [20]. For surgical interventions such as transoral or posterolateral odontoidectomy, precise morphometric information is crucial to minimize complications. In the present analysis, odontoid height, anteroposterior diameter, and transverse dimensions were recorded for surgical reference. The mean odontoid height (17.60 mm) was comparable to previous data [21-23] but slightly higher than other reported measurements [12,24,25]. The anteroposterior diameter (10.61 mm) and maximum transverse width (9.78 mm) were similar to values documented in both Indian and international studies [6,16,25]. The minimum transverse width (8.53 mm) and the atlanto-odontoid facet dimensions height (9.67 mm) and width (7.86 mm) were slightly lower than earlier reported averages [12,16,23,24]. These findings emphasize subtle population-related differences that may influence implant design and surgical planning.

Developmental or acquired alterations of the dens can modify its anatomical relationship with the anterior arch of the atlas. A hypoplastic odontoid process may lie below the upper margin of the anterior arch, while a hypertrophic dens may project into the foramen magnum, risking compression of the brainstem [26]. A distinct separation of the upper dens, known as *Os Odontoideum*, may occur congenitally or as a sequela of early childhood trauma and has notable medicolegal implications [27].

Morphological evaluation of the odontoid process revealed three major curvature patterns: lordotic, kyphotic, and straight. In this study, the lordotic form was most frequent, supporting the functional correlation between cervical curvature and the morphology of the dens [28,29]. Analysis of the ventral and dorsal facets demonstrated that the vertical elliptical ventral facet and the horizontal elliptical dorsal facet were predominant. These configurations are consistent with prior anatomical observations and suggest functional adaptation of the axis vertebra to cervical biomechanics.

Conclusion:

The morphometric measurements of the body of the axis and its odontoid process are crucial for spine and orthopedic surgeons when performing surgeries on the axis. These

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measurements are essential for the safe and effective application of modern orthopedic techniques, particularly in selecting the appropriate screw size for anterior trans-odontoid screw fixation in odontoid fractures or occipito-cervical fixation procedures. A comprehensive understanding of the axis vertebra and cervical spine anatomy is crucial as surgical tools continue to evolve. This knowledge aids in the design of trans-pedicle, trans-laminar, and trans-odontoid screws and prostheses used in surgeries. Such information assists surgeons in minimizing risks such as injury to the vertebral artery, damage to cranial nerves, and harm to other critical structures during interventional or surgical procedures in the cranio-vertebral region.

Limitations

This study is not without limitations. The cross-sectional design precludes establishing causal inferences regarding morphometric variations and their clinical implications. The sample size was relatively small (52 vertebrae) and restricted to a single institutional bone bank, limiting the generalizability of findings across populations. Age and sex of the specimens were unknown, preventing assessment of potential demographic differences. In addition, only dry vertebrae with preserved morphology were included, excluding possible variations seen in pathological or deformed specimens. Finally, radiological correlations were not performed, which could have enhanced the clinical applicability of the morphometric parameters.

Recommendations

Future studies should incorporate larger and more diverse samples, including specimens with known demographic profiles, to provide comprehensive morphometric data. Correlating anatomical findings with imaging modalities and clinical cases would strengthen translational relevance. Standardizing measurement techniques across institutions can improve the comparability of results. Further research should also explore three-dimensional morphometric analysis and its implications in designing surgical tools and implants to optimize patient safety.

Acknowledgement

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List of Abbreviations

VBL – Vertebral body length
VBSW – Vertebral body superior width
VBIW – Vertebral body inferior width
VBAH – Vertebral body anterior height
VBPH – Vertebral body posterior height
OPH – Odontoid process height
OPD – Odontoid process anteroposterior diameter
OPW-Max – Maximum transverse diameter of the odontoid process
OPW-Min – Minimum transverse diameter of the odontoid process
AOFH – Atlanto-odontoid facet height
AOFW – Atlanto-odontoid facet width

Source of Funding

This study received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability

The datasets generated and analyzed during the present study are available from the corresponding author upon reasonable request.

Author Biography

Dr Adabala N. V. V. Veerraju, MBBS (1993), MD Anatomy (2012), is a Professor in the Department of Anatomy at Konaseema Institute of Medical Sciences & Research Foundation, Amalapuram, achieving his current role in March 2025 after serving as Associate Professor (2022–2024) and earlier as Assistant Professor at Rangaraya Medical College (2017–2021). Educated under Dr NTR University of Health Sciences—earning his MBBS from Siddhartha Medical College and MD from Rangaraya Medical College—Dr Veerraju has a notable track record in anatomical research and medical education.

His scholarly contributions include studies on medical students' emotional responses to cadaveric dissection and the influence of the cadaveric oath, addressing both ethical and pedagogical dimensions of anatomy training. Morphometric investigations have ranged from intracapsular knee ligaments to meniscal structures and the styloid process in adult skulls, each enhancing anatomical knowledge with clinical relevance. Dr Veerraju's work reflects a dedicated pursuit of anatomical precision and

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educational insight, combining morphological rigor with a compassionate approach to medical teaching.**ORCID iD:** https://orcid.org/0009-0005-2901-2683

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