

ORIGINAL ARTICLE

Musculoskeletal Imaging

Morphometric and Volumetric Analysis of Odontoid Process Using Cone Beam Computed Tomography

Dr. Karthikeya Patil¹, Dr. Sanjay C J¹, Dr. Varusha Sharon Christopher¹,
Dr. Namrata Suresh¹, Dr. Vidya Gowdappa Doddawad², Dr. Ritu Basavarajappa¹

¹ Department of Oral Medicine and Radiology, JSS Dental College and Hospital,
JSS Academy of Higher Education and Research

² Department of Oral Medicine and Radiology, JSS Dental College and Hospital,
JSS Academy of Higher Education and Research

SUBMISSION: 16/11/2025 | ACCEPTANCE: 04/09/2026

ABSTRACT

This study investigates the morphometric and volumetric characteristics of the odontoid process in an Indian population using cone beam computed tomography (CBCT). The research analysed 60 subjects (30 male and 30 female) aged 18-60 years, examining parameters such as volume, maximum internal and external transverse diameters, anterior-posterior length, apex

to body length, maximum vertical length, and odontoid retroversion angle. Significant sex-based differences were observed in most dimensions, with males generally exhibiting larger measurements. Volume showed significant variations across both sex and age groups. The study revealed important population-specific data, highlighting differences from previous research in oth-



KEY WORDS

Odontoid Process, Cone Beam Computed Tomography, Anatomic Variation, Morphometry



CORRESPONDING AUTHOR, GUARANTOR

Dr. Sanjay C J, Reader, Department of Oral Medicine and Radiology, JSS Dental College and Hospital, JSS Academy of Higher Education and Research, Mysuru - 570015, Karnataka, India
Email: drsanjaycj_dch@jssuni.edu.in
Tel: +91 97425 65566

er populations. CBCT proved valuable for detailed odontoid morphometrics, though limitations such as poor soft tissue contrast were noted. The findings contribute to improving diagnostic accuracy, surgical planning, and understanding of cervical spine biomechanics in the Indian population. The research emphasises the importance of population-specific and sex-specific data in clinical applications, particularly for surgical interventions involving the odontoid process. Future studies are recommended to employ multi-modal imaging approaches and larger, more diverse population samples to further refine our understanding of odontoid process variations across different demographic groups.

Introduction

The odontoid process, also known as the dens, is a critical anatomical structure of the upper cervical spine that plays a pivotal role in atlantoaxial articulation and overall cervical stability [14]. This tooth-like projection, emanating from the superior aspect of the axis (C2 vertebra), serves as the fulcrum for rotational movements of the atlas (C1 vertebra), thereby facilitating the intricate biomechanics of head rotation. Its unique morphology allows it to articulate with the anterior arch of the atlas, forming the median atlantoaxial joint. This articulation, in conjunction with the lateral atlantoaxial joints, enables a remarkable range of motion, permitting approximately 50% of cervical spine rotation. The structural integrity of the odontoid process is maintained by a complex ligamentous system, including the transverse ligament of the atlas and the alar ligaments, which collectively ensure stability during dynamic movements and resist excessive translation of C1 onto C2 [2].

The clinical significance of the odontoid process cannot be overstated. Its strategic location at the craniocervical junction renders it susceptible to various pathological conditions, including traumatic fractures, congenital malformations, degenerative changes, and inflammatory processes such as rheumatoid arthritis. These conditions can lead to atlantoaxial instability, potential neurological deficits, and even life-threatening complications if left undiagnosed or improperly managed. To better understand these conditions, the morphometry of the normality of this structure needs to be well understood to properly understand its respective pathologies and deformities [13].

Accurate imaging paired with comprehensive radiological anatomy of the odontoid process is paramount for proper diagnosis, treatment planning, and post-intervention follow-up [10]. Conventional radiography, computed tomography (CT), magnetic resonance imaging (MRI), and cone-beam computed tomography (CBCT) represent the primary imaging modalities utilised in the evaluation of this structure. Each modality offers distinct advantages and limitations in terms of radiation exposure, soft tissue visualisation, and three-dimensional reconstruction capabilities.

Among these imaging techniques, CBCT has emerged as a superior option for odontoid process evaluation. This advanced imaging modality offers high-resolution, isotropic 3D images with reduced radiation exposure compared to conventional CT. The ability of CBCT to provide detailed osseous anatomy, multiplanar reconstructions, and volumetric data makes it an invaluable tool for assessing the complex morphology and spatial relationships of the odontoid process [7]. Many studies have been conducted for this structure through the dry skull [1, 5, 11, 17], but standardised linearity, calibration, and reproducibility can be achieved through the 3D imaging modality, and very few studies have explored this area; in particular, CBCT studies are scarce. This study aims to provide a comprehensive morphometric and volumetric analysis of the odontoid process, elucidating its anatomical nuances and clinical relevance through cone beam computed tomography.

Material and Methods

The study was conducted in a monocentric setting and was a descriptive retrospective study. The study included 60 subjects using a straightforward purposive sampling technique within the age range of 18 to 60 years. The institutional ethical review board approved the study with the following inclusion and exclusion criteria.

Inclusion criteria

- Optimally diagnostic quality CBCT images
- CBCT scans that indubitably display the structure of the skull base

Exclusion criteria

- Image with the presence of any developmental anomaly/ central pathology involving the cervical vertebra.

- Image with any evidence of previous surgery, fracture, or healed fracture of the cervical vertebra.
- Nondiagnostic CBCT images, including partial images or the presence of artefacts in the cervical vertebra.
- Radiographs satisfying the inclusion criteria were subjected to analysis for the following landmarks in axial and coronal dimensions in Planmeca Romexis 5.3 (3D software, Planmeca Oy, Helsinki, Finland) retrospectively sourced from the archives of the institution's data set.

Volume: Segmentation done through the software after delimitation of boundaries through ITK/SNAP software. (Figure 1)

Maximum Internal Transverse Diameter: Measurement of internal transverse diameter of odontoid process from interior cortex outline at the neck of odontoid process in the coronal view. (Figure 2)

Maximum External Transverse Diameter: Measurement of the external transverse diameter of the odontoid process from the exterior cortex outline at the neck of the odontoid in the coronal view. (Figure 2)

Anterior - Posterior Length: The distance from the most anterior to the most posterior point of the odontoid process in the sagittal plane. (Figure 3)

Apex to Body Length: The vertical distance from the tip (apex) of the odontoid process to its base, where it joins the body of the axis. (Figure 4)

Maximum Vertical Length: The maximum superior-inferior distance of the odontoid process involving the vertebral body. (Figure 5)

Odontoid Retroversion Angle: The angle between the long axis of the odontoid process and a line perpendicular to the posterior aspect of the C2 vertebral body. (Figure 6)

Statistical Analysis

Following data tabulation and statistical analysis, a comparison among the sexes and age groups was carried out. An independent computation of the mean, SD, p, and t values was performed. The gathered data was subsequently put through the Kolmogorov-Smirnov test and descriptive statistics to determine normality. Given the normal distribution of the data, an independent sample two-tailed t-test was conducted to find variability among sexes and an ANOVA was carried out for different age groups. A p-value of less than or equal to

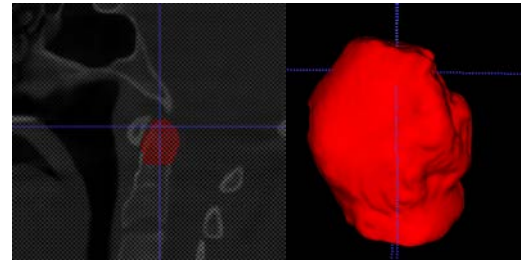


Figure 1: Segmentation of the odontoid process in ITK/SNAP software for measurement of volume.

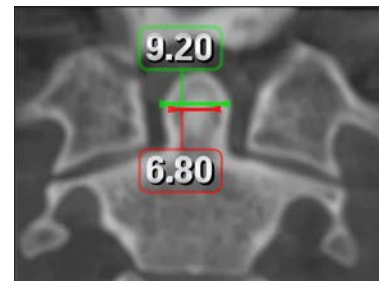


Figure 2: Maximum Extrenal Transverse Diameter (green line) and Maximum Inetrnal Transverse Diameter (red line).

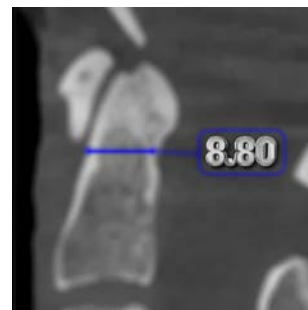


Figure 3: Anterior Posterior length

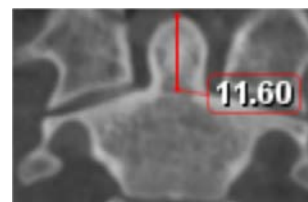


Figure 4: Apex to body length

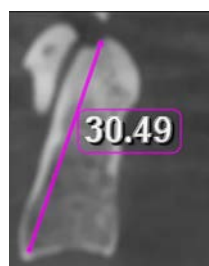


Figure 5: Maximum Vertical Length



Figure 6: Odontoid Retroversion Angle

0.05 was considered statistically significant. The statistical analysis was carried out using SPSS version 23.0.

Results

Among the 60 subjects whose CBCT scans were scrutinised, 30 were male and 30 were female, with a mean age of 37.48 years. Table 1 depicts the descriptive statistics based on sex and Table 2 depicts the descriptive statistics based on the various age group.

The independent samples t-test revealed statistically significant differences between the groups for several anatomical measurements (Table 3). Notably, Volume (mm³), Maximum Internal Transverse Diameter, and Maximum External Transverse Diameter exhibited highly significant disparities ($p < .001$), indicating substantial morphological variation. Anterior-posterior length and apex-to-body length also demonstrated significant differences ($p = .002$ and $p = .038$, respectively), albeit with less pronounced effect sizes. Conversely, Maximum Vertical length approached but did not attain statistical significance ($p = .076$), while the Odontoid retroversion angle showed no significant inter-group variation ($p = .670$). These findings suggest considerable anatomical distinctions between the groups, particularly in transverse dimensions and volu-

metric parameters, with less pronounced differences in vertical and angular measurements. (Figure 7)

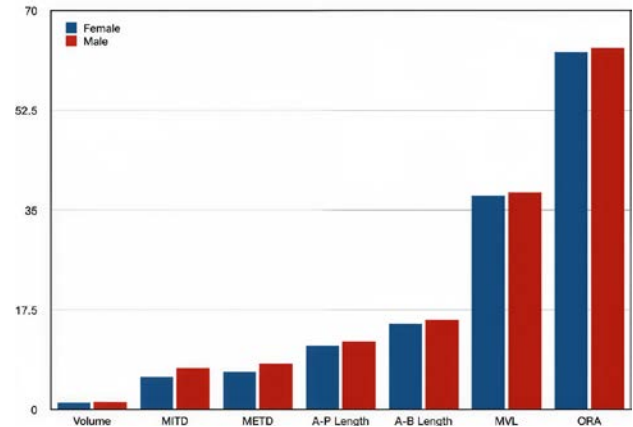


Figure 7: Sex wise differences in the measured parameters

The one-way analysis of variance (ANOVA) results reveal a statistically significant difference among the groups for volume (mm³) ($F(3, df) = 4.015$, $p = 0.012$), indicating substantial variability in this parameter across the examined categories (Table 4). However, the remaining anatomical measurements—including maximum internal and external transverse diameters, anterior-posterior length, apex to body length, maximum

Table 1: Descriptive Statistics based on Sex

Parameters	Sex	Mean	Std. Deviation	Coefficient of variation
Volume (cm ³)	Female	1.232	0.55	0.045
	Male	1.328	0.99	0.075
Maximum Internal Transverse Diameter (in mm)	Female	5.659	0.648	0.115
	Male	7.252	1.094	0.151
Maximum External Transverse Diameter (in mm)	Female	6.556	0.689	0.105
	Male	8.099	1.090	0.135
Anterior posterior length (in mm)	Female	11.247	0.705	0.063
	Male	11.857	0.755	0.064
Apex to body length (in mm)	Female	15.040	1.388	0.092
	Male	15.717	1.046	0.067
Maximum Vertical length (in mm)	Female	37.550	1.277	0.034
	Male	38.143	1.268	0.033
Odontoid retroversion angle (in°)	Female	62.687	6.875	0.110
	Male	63.497	7.732	0.122

Table 2: Descriptive Statistics based on Age Group

Parameters	Age group	Mean	Std. Deviation	Coefficient of variation
Volume (cm ³)	18-25	1.214	0.107	0.088
	26-35	1.302	0.102	0.079
	36-45	1.312	0.076	0.058
	Above 45	1.230	0.064	0.053
Maximum Internal Transverse Diameter (in mm)	18-25	6.500	1.165	0.179
	26-35	6.639	1.307	0.197
	36-45	6.636	1.223	0.184
	Above 45	5.916	0.954	0.161
Maximum External Transverse Diameter (in mm)	18-25	7.265	1.230	0.169
	26-35	7.551	1.300	0.172
	36-45	7.552	1.147	0.152
	Above 45	6.714	0.959	0.143
Anterior posterior length (in mm)	18-25	11.100	0.908	0.082
	26-35	11.610	0.729	0.063
	36-45	11.780	0.720	0.061
	Above 45	11.336	0.853	0.075
Apex to body length (in mm)	18-25	14.800	1.459	0.099
	26-35	15.520	1.482	0.096
	36-45	15.215	0.773	0.051
	Above 45	15.657	1.433	0.092
Maximum Vertical length (in mm)	18-25	38.017	0.343	0.009
	26-35	37.900	1.333	0.035
	36-45	37.680	1.361	0.036
	Above 45	37.936	1.488	0.039
Odontoid retroversion angle (in°)	18-25	61.283	7.934	0.129
	26-35	62.725	7.058	0.113
	36-45	63.055	7.740	0.123
	Above 45	64.443	7.160	0.111

vertical length, and odontoid retroversion angle—did not exhibit statistically significant inter-group differences (all $p > 0.05$). These findings suggest that while volumetric disparities exist among the groups, other linear and angular dimensions remain relatively consistent. The lack of significant variation in most parameters implies a degree of morphological homogeneity across groups, with the exception of volume, which

emerges as a distinguishing factor. This analysis underscores the importance of considering volumetric measurements in future investigations of anatomical variation within this context. (Figure 8)

Discussion

The development of the odontoid process, also known as the dens of the axis (second cervical vertebra), is a

Table 3: Independent Samples T-Test

Parameters	t	df	p
Volume (mm ³)	-4.600	45.566	< .001
Maximum Internal Transverse Diameter	-6.861	47.151	< .001
Maximum External Transverse Diameter	-6.552	48.965	< .001
Anterior posterior length	-3.235	57.724	0.002
Apex to body length	-2.132	53.911	0.038
Maximum Vertical length	-1.806	57.997	0.076
Odontoid retroversion angle (in°)	-0.429	57.218	0.670

Table 4: ANOVA among the age groups

Parameters	Sum of Squares	df	Mean Square	F	p
Volume (mm ³)	91236.921	3	30412.307	4.015	0.012
Maximum Internal Transverse Diameter	5.423	3	1.808	1.273	0.292
Maximum External Transverse Diameter	7.312	3	2.437	1.781	0.161
Anterior posterior length	2.988	3	0.996	1.664	0.185
Apex to body length	4.030	3	1.343	0.832	0.482
Maximum Vertical length	0.897	3	0.299	0.170	0.916
Odontoid retroversion angle (in°)	47.896	3	15.965	0.292	0.831

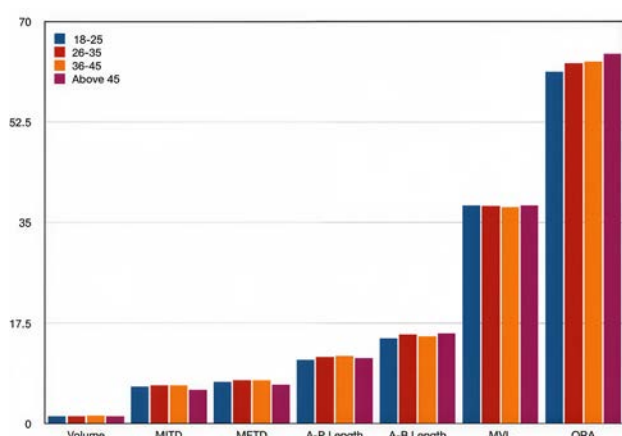


Figure 8: Age wise difference among the parameters

complex and unique process in vertebral embryology. It begins during the foetal period and continues well into early childhood. The odontoid process originates from the body of the first cervical vertebra (atlas) and fuses with the body of the axis. This fusion typically occurs between the ages of 3 and 6 years. The process develops from two primary ossification centres that

appear around the 5th to 6th months of foetal life. An additional secondary ossification centre, known as the ossiculum terminale, appears at the apex of the odontoid around age 3-5 years and fuses by age 12. This prolonged developmental timeline makes the odontoid process particularly vulnerable to congenital anomalies and traumatic injuries in children [2, 9].

Traumatic injuries to the odontoid process are significant due to the structure's critical role in atlantoaxial stability. Odontoid fractures are classified into three types based on the fracture location: type I (avulsion of the tip), type II (fracture at the base), and type III (extending into the axis body). Type II fractures are the most common and have a higher risk of nonunion due to poor blood supply.

Other traumatic injuries include atlantoaxial dislocation and transverse ligament disruption [3, 4]. Non-traumatic pathologies affecting the odontoid include congenital anomalies like os odontoideum (separation of the odontoid from the axis body), hypoplasia, and aplasia. Inflammatory conditions such as

rheumatoid arthritis can lead to erosion of the odontoid and subsequent atlantoaxial instability. Degenerative changes may result in crowned dens syndrome, characterised by calcium pyrophosphate deposition around the odontoid. Infections like osteomyelitis and tumours, both primary and metastatic, can also involve the odontoid, potentially leading to instability and neurological deficits [8, 18].

Morphometric analysis of the odontoid process plays a crucial role in navigating traumas and pathologies affecting this structure. By providing detailed measurements and anatomical relationships, morphometrics aids in diagnosis, surgical planning, and risk assessment. These morphometrics help in determining the severity of fractures, the degree of displacement in dislocations, and the extent of pathological changes in conditions like rheumatoid arthritis. For surgical interventions, such as screw fixation in odontoid fractures, precise morphometric data is essential for selecting appropriate screw sizes and trajectories, thus minimising the risk of neurovascular injury.

In cases of congenital anomalies or degenerative changes, morphometrics can quantify the degree of malformation or stenosis, guiding treatment decisions. Additionally, population-based morphometric studies contribute to our understanding of normal variations, helping to distinguish pathological changes from anatomical variants.

The current study revealed significant sex-based differences in odontoid process dimensions, with males consistently showing larger measurements than females. The maximum internal and external transverse diameters, as well as the Anterior-Posterior length, demonstrated highly significant differences ($p < 0.001$). The apex to body length also showed a significant difference ($p = 0.038$), while the maximum vertical length and odontoid retroversion angle did not reach statistical significance ($p = 0.076$ and $p = 0.670$, respectively). These findings align with those of Uthman et al., who also reported substantially larger transverse and AP diameters in males compared to females [16].

Studies done by Korres et al. and Tun et al. also compared the morphometrics of the odontoid process but Korres et al. failed to report any significance in their findings [12, 15]. Similar to Uthman et al.'s study, which found no significant impact of age on odontoid morphometrics, the present study results also have not

concluded with any significance, though further investigation may be needed to fully elucidate this relationship [16]. The differences in external transverse diameter distributions between our population and those reported by Uthman et al. highlight the importance of population-specific data in surgical planning, particularly for procedures involving screw placement in the odontoid process.

The volume of the odontoid process is a significant morphometric parameter that offers a comprehensive view of its three-dimensional structure. This measurement is valuable in assessing the severity of erosive diseases like rheumatoid arthritis and in evaluating anomalies such as os odontoideum.

This study assessed the volume of the odontoid process, which showed significant differences regarding sexual dimorphism as well as in age groups. Studies on the volumetric analysis of the odontoid process are very limited. On a literature search, only one study conducted by Costa et al. gave evidence of significant sexual variation in volume; however, the study had an insignificant correlation when compared across age groups [6].

The discrepancy between the current study involving the Indian population and Costa et al.'s Brazilian population based study can be attributed to genetic, environmental, and methodological differences. These contrasting results highlight the importance of population-specific studies and standardised methodologies in odontoid process morphometrics.

Conclusion

This morphometric study of the odontoid process in an Indian population using CBCT reveals significant sex-based differences in odontoid dimensions, with males generally exhibiting larger measurements. Our findings align with previous studies while providing a more comprehensive analysis.

The observed variations in odontoid volume among age groups and between sexes emphasise the importance of population-specific data in clinical applications.

While CBCT proves valuable for odontoid morphometrics, it has limitations, such as poor soft tissue contrast. This study contributes vital data for improving diagnostic accuracy, surgical planning, and understanding of cervical spine biomechanics in the Indian popula-

tion. However, the complexity of odontoid morphology and CBCT limitations suggest that future research should consider multi-modal imaging approaches and

larger, diverse population samples to further refine our understanding of odontoid process variations across different demographic groups. **R**

REFERENCES

1. H. Abdulameer. 2010. Morphometric analysis of the odontoid process. *Iraqi Journal of Medical Sciences* (2010). Retrieved from https://www.researchgate.net/profile/Hayder-Abdul-Ameer/publication/330566417_Morphometric_analysis_of_odontoid_process/links/5f99890292851c14bcd886c/Morphometric-analysis-of-odontoid-process
2. Seleipiri Akobo, Elias Rizk, Marios Loukas, Jens R. Chapman, Rod J. Oskouian, and R. Shane Tubbs. 2015. The odontoid process: a comprehensive review of its anatomy, embryology, and variations. *Childs. Nerv. Syst.* 31, 11 (November 2015), 2025–2034.
3. N. J. Blockley and D. W. Purser. 1956. Fractures of the odontoid process of the axis. *J. Bone Joint Surg. Br.* 38-B, 4 (November 1956), 794–817.
4. Jörg Böhler. 1965. FRACTURES OF THE ODONTOID PROCESS. *J. Trauma Acute Care Surg.* 5, 3 (May 1965), 386.
5. E. M. Corner. 1907. Fractures of the Odontoid Process of the Axis. *Med. Chir. Trans.* 90, (1907), 637–665.
6. André Luiz Ferreira Costa, Ana Amelia Barbieri, Bianca Costa Gonçalves, Camila Felisbino Silva, Celso Massahiro Ogawa, Cristiane de Almeida Baldini Cardoso, Karolina Aparecida Castilho Fardim, and Sérgio Lucio Pereira de Castro Lopes. 2021. Cone Beam Computed Tomography Based Sex Estimation by Volume of Odontoid Process of The Second Cervical Vertebra. *BDS* 24, 3 (July 2021). <https://doi.org/10.14295/bds.2021.v24i3.2538>
7. Jean-Philippe Dillenseger, Jean-François Matern, Catherine-Isabelle Gros, Fabien Bornert, Christian Goetz, Jean-Marie Le Minor, André Constantinesco, and Philippe Choquet. 2015. MSCT versus CBCT: evaluation of high-resolution acquisition modes for dento-maxillary and skull-base imaging. *Eur. Radiol.* 25, 2 (February 2015), 505–515.
8. Brian Fiani, Rebecca Houston, Imran Siddiqi, Mohammad Arshad, Taylor Reardon, Brandon Gilliland, Cyrus Davati, and Athanasios Kondilis. 2021. Retro-Odontoid Pseudotumor Formation in the Context of Various Acquired and Congenital Pathologies of the Craniovertebral Junction and Surgical Techniques. *Neurospine* 18, 1 (March 2021), 67–78.
9. Michitake Ishii, Kwang Ho Cho, Kei Kitamura, Masahito Yamamoto, Gen Murakami, José Francisco Rodríguez-Vázquez, and Shin-Ichi Abe. 2021. Development and growth of the craniocervical junction with special reference to topographical relationship between the occipital basion, the anterior arch of atlas, and the odontoid process of axis: A study using human fetuses. *Anat. Rec.* 304, 2 (February 2021), 353–365.
10. Kivanç Kamburoğlu, Eray Kolsuz, Hakan Kurt, Cenç Kiliç, Tuncer Özen, and Candan Semra Paksoy. 2011. Accuracy of CBCT measurements of a human skull. *J. Digit. Imaging* 24, 5 (October 2011), 787–793.
11. Z. Khaleel, D. Besachio, E. Bisson, and L. Shah. 2014. Estimation of odontoid process posterior inclination, odontoid height, and pB-C2 line in the adult population. *J. Neurosurg. Spine* 20, 2 (February 2014), 172–177.
12. D. S. Korres, J. Lazaretos, J. Papailiou, E. Kyriakopoulos, D. Chytas, N. E. Efstathopoulos, and V. S. Nikolaou. 2016. Morphometric analysis of the odontoid process: using computed tomography—in the Greek population. *Eur. J. Orthop. Surg. Traumatol.* 26, 2 (February 2016), 119–125.
13. Nicola Montemurro, Ardico Cocciaro, Gaetano Liberti, Mirco Cosottini, and Paolo Perrini. 2022. The internal trabecular bone structure of the odontoid process of the axis. A retrospective single-center comparative study in patients following cervical trauma. *J. Neurol. Surg. A Cent. Eur. Neurosurg.* (October 2022). <https://doi.org/10.1055/a-1962-0181>
14. R. Shane Tubbs. 2020. The Odontoid Process. In *The Chiari Malformations*, R. Shane Tubbs, Mehmet Turgut and W. Jerry Oakes (eds.). Springer International Publishing, Cham, 129–135.
15. Kagan Tun, Erkan Kaptanoglu, Berker Cemil, Mehmet Yorubulut, S. Tuna Karahan, and Ibrahim Tek-

- demir. 2009. Anatomical study of axis for odontoid screw thickness, length, and angle. *Eur. Spine J.* 18, 2 (February 2009), 271–275.
16. Asmaa Uthman, Basheer Salman, Hawraa Shams Al-deen, Hesham Marei, Sura F. Al-Bayati, and Natheer H. Al-Rawi. 2023. Morphometric analysis of odontoid process among Arab population: a retrospective cone beam CT study. *PeerJ* 11, (May 2023), e15411.
17. W. Wang, X. Wang, X. Ren, Z. Li, B. Su, Y. Xu, X. Xu, D. Lv, W. Liu, S. Zhang, L. Chen, and X. Li. 2020. Features and clinical significance of the ossification centres in the odontoid process based on micro-computed tomography. *Folia Morphol.* 79, 4 (2020), 845–850.
18. Francesco Zenga, Paolo Pacca, Valentina Tardivo, Valentina Pennacchietti, Diego Garbossa, Giancarlo Pecorari, and Alessandro Ducati. 2016. Endoscopic Endonasal Approach to the Odontoid Pathologies. *World Neurosurg.* 89, (May 2016), 394–403.

READY-MADE
CITATION

Dr. Karthikeya Patil, Dr. Sanjay C J, Dr. Varusha Sharon Christopher, Dr. Namrata Suresh, Dr. Vidya Gowdappa Doddawad, Dr. Ritu Basavarajappa. Morphometric and Volumetric Analysis of Odontoid Process Using Cone Beam Computed Tomography, *Hell J Radiol* 2026; 11(3): 22-30.