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Original Article

Anatomy Section

Morphometric Anatomy of Atlas (C1) and Axis (C2) on Dry Bones versus CT Scan Images: A Cross-sectional Study from Southern India

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ABSTRACT

Introduction: The uniqueness of the atlas (C1) and axis (C2) cervical vertebrae helps in transmitting weight from the cranial cavity to the rest of the vertebral column. A detailed understanding of the C1 and C2 morphometric dimensions is essential for evaluating treatment protocols such as screw placement and intralaminar fixations to provide stability for the occipitocervical complex. Computerised Tomography (CT) scan images are best for demonstrating the osseous margins.

Aim: To assess the relationship between the linear morphometric measurements of the CT images and dry C1 and C2 vertebrae.

Materials and Methods: A descriptive, cross-sectional study was conducted using 35 atlas (C1) and 35 axis (C2) dry bones from the Department of Anatomy, Karuna Institute of Medical Sciences, Palakkad, Kerala, India, from August 2023 to October 2023. A total of 35 CT scan images were also taken for the study. Siemens Syngo software tool was utilised to assess the C1 and C2 vertebrae. Measurements of the vertebral canal, foramen transversarium, superior articular facets, vertebral artery groove, dens, and body were performed on dry C1, C2, and CT images. Descriptive statistics were evaluated using mean, standard deviation, percentage difference, and mean deviation. The unpaired t-test was used to test significance, with p-value <0.05 considered statistically significant.

Results: Concerning the anatomical parameters, between the dry C1 and CT scan images, all linear parameters were statistically significant (p-value <0.05), except for the vertebral artery groove-inner and outer distances, which were not statistically significant. Regarding C2, when comparing anatomical parameters between dry vertebrae and CT scan images, the width of the body and the length of the vertebral canal were not statistically significant, while all other C2 parameters were statistically significant (p-value <0.05).

Conclusion: The results obtained from the study on the atlas and axis may be valuable for operating surgeons during surgical procedures in the craniovertebral region. The present study also aids in preventing iatrogenic complications, including vertebral neurovascular injuries, and provides a roadmap for skilled surgical access.

Keywords: Computerised tomography scan, Dens, Foramen transversarium, Vertebral artery

INTRODUCTION

Atlas (C1) and axis (C2) vertebrae are atypical, possessing distinct morphological features and functions. The uniqueness of C1 lies in its role in transmitting weight from the cranial cavity to the rest of the vertebral column. Unlike other vertebrae, it lacks a body, allowing it to rotate with the dens of C2 and contribute to the median atlanto-occipital joint. C2 articulates with C1 and the third cervical vertebra, featuring a unique dens or odontoid process and specialised superior articular facets. The dens protrudes cranially from the superior surface of the C2 body, serving as an axle for rotation of C1 [1].

The term "atlas" pays homage to the Greek mythology character, Hemithius Atlas, who carried the globe of heavens on his shoulders. As the nodding action occurs in the C1 bone, it is referred to as the 'YES' bone [2]. C1 articulates superiorly with the occipital bone to form the atlanto-occipital joint, while inferiorly it articulates with C2 to form the atlanto-axial joint. C1 is considered an intercalated segment as it acts as a bridge between the cranial cavity and C2 [3].

After exiting the foramen transversarium, the third part of the vertebral artery loops behind the lateral mass and rests in the neurovascular depression on the posterior arch of C1. Clinically, this groove is referred to as the sulcus arteria vertebralis or the sulcus for the vertebral artery [4,5].

A comprehensive understanding of C2 dimensions is essential for evaluating treatment protocols such as screw placement and intralaminar fixations to provide stability for the occipitocervical complex. Screw fixation over the lateral mass restores anatomical stability in the cervical region [6]. CT scans, the latest revolutionary imaging technique, accurately reproduce osseous structures. The craniovertebral junction plays a critical role in surgical interventions for vertebral dislocations and traumatic fractures [7,8].

Previous studies on morphometric measurements were mainly focused on dry C1 or C2 vertebrae [4-6,8-11]. A prior study assessed morphometric measurements using CT scan images among the Indian population, but only for C1 vertebrae [7]. Therefore, the present study aimed to evaluate the relationship between morphometric measurements of dry C1 and C2 with CT scan images among the Indian population.

MATERIALS AND METHODS

A descriptive, cross-sectional study was conducted using 35 atlas (C1) and 35 axis (C2) dry bones from the Department of Anatomy, Karuna Institute of Medical Sciences, Palakkad, Kerala, India, from August 2023 to October 2023, after obtaining Ethical Clearance from the committee via letter numbered KMC/IHEC/14/2023. The data for CT images (n=35) were obtained from the Department of Radiology, Karuna Medical College, Kerala.

Sample size calculation: The sample size selection was finalised based on studies by Gupta C et al., on dry C1 and C2 among the South Indian population at Manipal and Naderi S et al., for CT images among the Turkish population [3,4]. CT scan images (n=35) were captured using a CT spiral scanner with multiple slices (Somatom Spirit (79627), SIEMENS AG, from Germany). Axial and coronal sections of CT scan images in the cervical region, C1 and C2, were separately evaluated from the same patients.

Inclusion criteria: It consisted of intact and undistorted Dry C1 and C2 vertebrae selected from the Department of Anatomy. CT scan images in the cervical region from patients who attended routine health check-ups were considered for the study.

Exclusion criteria: It included occipitalisation of C1, foetal C1 and C2, macerated C1 and C2, distorted C2, C2 with an imperfect dens, and vertebrae with osteophytes. CT images with soft tissue pathologies, osseous distortions, image distortions, and infant images were also excluded from the study [9].

Study Procedure

Stainless Steel Vernier callipers were used for measuring the dry C1, C2 [Table/Fig-1] and the Siemen's Syngo software distance tool for measuring C1 and C2 in the CT images. Operational definitions for the parameters studied current research work were defined.

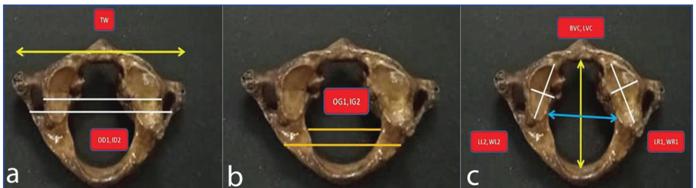
Study on the atlas vertebrae (C1): Morphometric measurements of dry C1 and C2 were taken using Vernier callipers [Table/Fig-1].

[Table/Fig-1]: Shows the dry atlas (C1) and the measuring tool- Stainless steel Vernier callipers.

The list of morphometric variables along with operational definitions for C1 are presented in [Table/Fig-2]. The morphometric linear parameters of dry C1 are shown with solid arrows [Table/Fig-3a-c].

Variables	Abbreviations
• Outer vertebral artery foramen distance	OD 1
• Inner vertebral artery foramen distance	ID 2
• Length of the vertebral canal	LVC
• Breadth of the vertebral canal	BVC
• Total width	TW
• Outer distance of vertebral artery groove	OG1
• Inner distance of vertebral artery groove	IG2
• Length of superior articular facet-right	LR 1
• Length of superior articular facet-left	LL 2
• Width of superior articular facet-right	WR 1
• Width of superior articular facet-left	WL 2

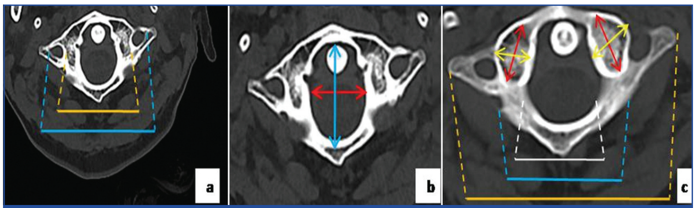
[Table/Fig-2]: List of morphometric variables assessed on dry Atlas (C1) and CT images.



[Table/Fig-3]: Displays the dry atlas (C1) with linear measurements. The morphometric dimensions of atlas studied were a) TW (yellow colour), OD1, ID2 (white colour); b) OG1,IG2 (orange); c) LL2, WL2, LR1, WR1 (white colour) of both right and left-sides, LVC (yellow colour), BVC (blue colour).

Atlas (C1) measurements on CT images are shown in [Table/Fig-4a-c].

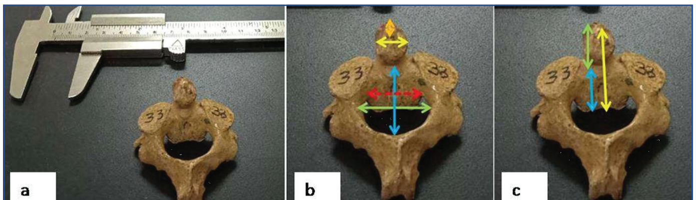
Study on the axis vertebra (C2): Morphometric linear parameters of dry C2 and CT images are depicted in [Table/Fig-5]. Dry C2 and CT images are shown in solid and dotted arrows [Table/Fig-6a-c] and [Table/Fig-7a-d] respectively].



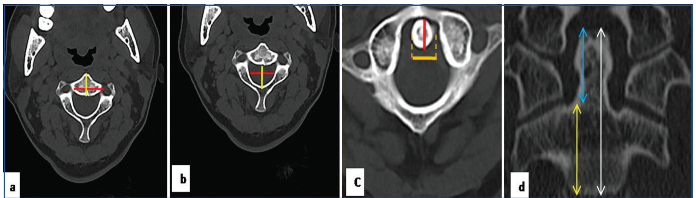
[Table/Fig-4]: Atlas (C1) on axial sections of CT images. a) Foramen Transversarium-inner margin inter-distance- ID2 (orange line) and outer margin inter-distance- OD1 (blue line); b) Anterioposterior Length of Vertebral Canal of C1- LVC (blue line), Width of vertebral canal of C1-BVC (red line); c) Total Width of C1-TW (orange line), outer distance between the vertebral artery groove-OG1 (blue line), inner distance between the vertebral artery groove- IG2, (white line), Superior articular facets-Length- LR1, LL2 and width- WR1,WL2 of right and left-sides (red and yellow lines).

Variables	Abbreviations
• Anteriopostерior diameter body	B AP
• Width of body	B W
• Height of body	B H
• Width of dens	D W
• Height of dens	D H
• Anterioposterior diameter of dens	D AP
• Total height	T H
• Anterioposterior diameter of vertebral canal	VC AP
• Width of vertebral canal	VC W

[Table/Fig-5]: Morphometric measurements that were assessed on dry Axis (C2) and CT images.



[Table/Fig-6]: a) Displays the dry axis (C2) vertebra with vernier callipers; b) showing the parameters- D AP (orange Colour), DW (yellow Colour), B W (red colour, dotted lines), VC AP (blue colour), VC W (green colour).1; c) BH (blue colour), DH (green colour), TH (yellow colour).



[Table/Fig-7]: C2 on axial sections- a) Body of axis- length BAP (Yellow line) and width BW (Red line). b) Anterioposterior Length of Vertebral Canal (LVC) of C2- VC AP(Yellow line), width of vertebral canal of C2- VC W (Red line); c) Dens anterior posterior diameter- DAP (Red line) and width -DW (Orange line).

STATISTICAL ANALYSIS

Data analysis was conducted using the Statistical Package for Social Sciences (SPSS) software version 21.0 package. Descriptive statistics were assessed using mean, standard deviation, percentage difference, and mean deviation. Inferential statistics were applied with an Unpaired t-test for variables to test significance. A p-value less than 0.05 was considered statistically significant.

RESULTS

The results of the morphometric measurements of C1 in the present study are presented in [Table/Fig-8]. The anatomical parameters were measured in dry C1 and CT scan images and are displayed in [Table/Fig-8]. Based on the current results, all C1 dimensions were statistically significant (p-value <0.05) except for the outer distance of the vertebral artery groove (OG1), the outer distance of the vertebral artery foramen (OD1), and TW.

The mean morphometric measurements of C2 in the present study are shown in [Table/Fig-9]. Inferences from [Table/Fig-9] indicate

Parameters	Dry C1 Mean	SD	CT scan Mean	SD	Mean diff.	% Diff.	p-value
OD 1	5.70	0.48	5.61	0.48	0.09	1.58	0.424
ID 2	4.58	0.36	4.41	0.30	0.17	3.71	0.048*
OG1	4.40	0.51	4.38	0.42	0.02	0.45	0.799
IG2	2.75	0.38	3.05	0.51	-0.3	-10.91	0.011*
LVC	2.45	0.20	2.72	0.39	-0.27	-11.02	<0.001**
BVC	2.35	0.19	2.85	0.69	-0.50	-21.38	<0.001**
TW	6.10	0.61	6.41	0.60	-0.31	-5.08	0.053
LR 1	2.00	0.40	1.75	0.40	0.25	12.50	0.011*
L L 2	2.04	0.36	1.72	0.29	0.32	15.69	<0.001**
WR 1	1.34	0.29	1.14	0.27	0.20	14.93	0.005*
WL 2	1.30	0.32	1.07	0.30	0.23	17.69	0.006*

[Table/Fig-8]: Shows the parameters of C1 dry bones (N=35) with CT scans (n=35) images.
Data shown is Mean, SD: Standard deviation, Mean difference, MD: Mean deviation and % Diff- Percentage difference. Unpaired t-test was used. Level of significance p<0.05 considered statistically significant; OD 1: Outer vertebral artery foramen distance; ID 2: Inner vertebral artery foramen distance; OG 1: Outer distance of vertebral artery groove; IG 2: Inner distance of vertebral artery groove; LVC: Length of the vertebral canal; BVC: Breadth of the vertebral canal; TW: Total width of C1; LR 1: Length of superior articular facet- Right; LL 2: Length of superior articular facet- Left; WR 1: Width of superior articular facet- Right; WL 2: Width of superior articular facet; Left. *Shows p-value significant, **Shows p-value highly significant

Parameters	Dry C2 Mean	SD	CT scan Mean	SD	Mean diff.	% Diff.	p-value
B AP	1.14	0.26	1.32	0.21	-0.08	-15.79	0.009*
B W	1.86	0.30	1.87	0.32	-0.01	-0.54	0.936
B H	1.64	0.15	1.80	0.31	-0.16	-9.76	0.004*
D W	0.54	0.10	0.78	0.22	-0.24	-44.44	<0.001**
D H	1.33	0.26	1.80	0.31	-0.47	-35.34	<0.001**
D AP	0.62	0.12	0.75	0.17	-0.13	-20.97	<0.001**
T H	3.14	0.26	2.74	0.43	0.40	12.74	<0.001**
VC W	1.78	0.20	2.20	0.33	-0.42	-23.60	<0.001**
VC AP	1.49	0.21	1.51	0.20	0.18	1.34	0.805

[Table/Fig-9]: Shows the parameters of C2 (N=35) with CT scan (N=35) images.
Data shown is Mean, SD: Standard deviation, mean difference deviation and percentage difference. Unpaired t-test was used. Level of significance- p<0.05 considered statistically significant. Anterioposterior diameter body of C2-B AP; Width of body of C2-B W, Height of body of C2- B H, Width of dens of C2- D W; Height of dens of C2- D H; Anterioposterior diameter of dens of C2-D AP; Total height of C2 T H; Anterioposterior diameter of vertebral canal VC AP; Width of vertebral canal-VC W; *Shows p-value significant; **Shows p-value highly significant

that when the anatomical parameters are compared between dry C2 and CT scan images, the width of the body and the anteroposterior diameter of the vertebral canal were not statistically significant (p-value <0.05), while the rest of all the C2 parameters were statistically significant.

DISCUSSION

Detailed knowledge of C1 and C2 is necessary as newer surgical techniques, such as the implementation of screw fixation, are emerging for unstable cervical spine treatments. Better understanding of the anatomical location in C1 can help minimise inadvertent injuries to the vertebral artery, venous plexus, and dorsal rami of the first cervical nerve [12,13].

The majority of the current research work on dry C1 is similar to studies conducted by Gupta C et al., Gosavi SN and Vatsalaswamy P and Shingare AK and Kawale DN on the Indian population and the current research work on CT images is similar to a study conducted by Bhide PC et al., [Table/Fig-10] [4,7-9]. Additionally, quantitative linear outer and inner measurements of the vertebral artery groove (OG1, IG2) were also similar to studies by Ravichandran D et al., 2011, and Sutha S 2017 in the study population [5,11].

In the present study results, there was no significant difference in the measurements of OD 1, OG 1, and TW between the dry C1 and CT scan measurements. Many of the mean parameters were similar to the study conducted by Patel NP and Gupta DS among the Indian population [14]. Ebraheim NA et al., stated that accidental damage to the vertebral artery can be avoided by staying medial to the groove and dissecting within 12 mm lateral to the midline [15].

Measurements of the outer and inner inter-distance of the vertebral artery foramen (OD1, ID2), LVC, breadth of the Vertebral Canal (BVC), and TW were in agreement with Senegul G and Kodiglu HH 2006 among the Turkish population and Lang J 2001 among the American population [16,17]. Similar to the present study, Naderi S et al., among the Turkish population, analysed the significance of the parameters between the study groups [3]. His study results revealed that the majority of the parameters were not significant except for the distance between vertebral artery grooves.

Assessment of the superior articular facets of C1 on either side is essential for surgical reduction and screw fixation techniques [18].

Linear parameters	Dry C1 (cm) Gupta C et al., (2013), India, [4]	Gosavi SN and Vatsalaswamy P (2012), India, [9]	Shingare AK and Kawale DN (2017], India, [8]	Present study findings	CT images (cm) Bhide PC et al., (2019), India, [7]	Present study findings
Superior articular facets						
Length						
Right- LR1	2.15	2.12	2.04	2.00	1.82	2.00
Left-side- LL1	2.18	2.10	2.07	2.04	1.84	2.04
Width						
Right- WR2	1.18	1.03	1.06	1.34	1.08	1.34
Left-side- WL2	1.15	1.04	1.04	1.30	1.09	1.30
Vertebral artery groove						
Outer distance OG1	4.5	-	-	4.40		
Inner distance IG2	2.5	-	-	2.75		
Vertebral artery foramen						
Outer distance OD1	5.76	5.56		5.70		
Inner distance ID2	4.52	4.59		4.58		
Vertebral canal						
Length LVC	3.0	2.6		2.45		
Breadth BVC	2.7	2.6		2.35		
Total Width TW	7.2	6.93		6.10		

[Table/Fig-10]: Literature review of anatomical parameters of dry Atlas (C1) and C1 CT images [4,7-9].

Both C1 and C2 have special characteristics in contrast to the rest of the cervical vertebrae. Surgical techniques such as laminar clamping, interspinous wiring, plates, and screw fixation have been employed to treat atlantoaxial complexities [19,20].

The majority of our current research work on dry C2 is similar to studies conducted by Gosavi S and Swamy V.,among the Indian population, and Xu R et al., Lu J et al., Dohert BJ and Heggeness MH, and Senegul G and Kodiglu HH among the international population [Table/Fig-11] [6,16,21-23].

Linear parameters	Dry C2 (cm)					
	Xu R et al., USA, (2013), [21]	Lu J et al., USA, (1995), [22]	Dohert BJ and Heggeness MH, America, [6]	Senegul G and Kodiglu HH, (2017), Turkey, [16]	Gosavi S and Swamy V (2012), India, [23]	Present study findings
Dens of C2						
Height				1.45	1.48	1.33
Body of C2						
Length			1.62		1.47	1.14
Height	2.11	2.04	2.33	2.21	2.04	1.64
Total height					3.42	3.14
Width	1.9		1.87		1.59	1.86
Vertebral canal of C2						
Width	2.19		2.36	24.7	2.15	1.78

[Table/Fig-11]: Literature review of anatomical parameters of dry Axis (C2) [6,16,21-23].

Morphometric measurements of C2 using CT images revealed that the width and length of the dens were greater in studies conducted by Acharya S et al., Daher MT et al., Kulkarni AG et al., and Yusof M et al., compared to the current study [24-27].

The findings of the present study showed that all the parameters of C2 were statistically significant, except for the width of the body and the length of the vertebral canal. Our present comparative study forms a baseline data for future forensic identification procedures.

Similar studies conducted by Jerković I et al., Corron Let al., Gaya-Sancho B et al., and Banik S et al., compared dry bone measurements with virtual digital imaging techniques and assessed the significance among them [28-31]. Banik S et al., found significantly higher values (p-value <0.001) for the vertebral body mid-diameter of S1, vertebral body height of S1, pedicle depth, and width measurements in the dry bone group compared to the CT scan group [31]. When comparing the mean values with studies of other populations, our results varied due to ethnicity and geographical factors.

This study showed that, dry bone osteometrics and virtual measurements from medical imaging were statistically significant. These results validated the osteometry and aids in forensic investigations.

Digital imaging techniques are essential for morphometric assessments of ethnicity. Cone Beam Computed Tomography (CBCT) and Multi-Detector Computed Tomography (MDCT) have higher resolution than a spiral CT scanner [28].

Limitation(s)

The statistical comparison of quantitative dimensions between the right and left articular facets was not included in the present study. Additionally, a qualitative analysis of the shapes of the superior articular facets in C1 and C2 was not conducted. Laminar thickness and angular measurements were not considered in the study design.

CONCLUSION(S)

The present study provides detailed knowledge of the morphometric analysis of dry C1 and C2 vertebrae using CT images, aiding in establishing a safety zone for surgical access. Limited resources were available to compare the linear measurements of dry cervical vertebrae with CT images. Therefore, the current work will lay a strong foundation for the C1 and C2 parameters that will assist in future studies.

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