



MORPHOMETRIC ANALYSIS OF DRY HUMAN ATLAS AND AXIS VERTEBRAE: ANATOMICAL CONSIDERATIONS FOR C1-C2 SCREW PLACEMENT

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ABSTRACT

Objective: This study aimed to evaluate the morphometric characteristics of dry human atlas (C1) and axis (C2) vertebrae and to assess their potential relevance for safe C1-C2 screw placement.

Materials and Methods: This descriptive osteometric and anatomical study included 35 dry human C1 vertebrae and 25 dry human C2 vertebrae. All measurements were performed directly on dry bones using a digital caliper with 0.01 mm precision. Right- and left-sided parameters were measured separately. Continuous variables were expressed as mean \pm standard deviation and minimum-maximum values. Right-left comparisons were performed using paired-samples t-tests, with $p < 0.05$ considered statistically significant.

Results: In C1, significant side-to-side differences were observed in the outer and inner distances of the vertebral artery groove, in the horizontal thickness of the lateral mass, and in the diameter of the vertebral foramen. The outer distance of the vertebral artery groove and the lateral mass horizontal thickness were significantly greater on the right side, whereas the inner distance of the vertebral artery groove and the vertebral foramen diameter were significantly greater on the left side. In C2, significant differences were found only in the anteroposterior diameter of the vertebral canal and in lamina length, both of which were greater on the right side. No significant bilateral differences were observed in most of the remaining C1 and C2 parameters.

Conclusion: Dry human C1 and C2 vertebrae exhibited measurable bilateral morphometric variations, particularly in parameters related to the C1 vertebral artery groove and in C2 lamina length. These findings may contribute to anatomical knowledge relevant to craniovertebral junction surgery and support individualized, side-specific preoperative evaluation before screw fixation.

Keywords: Atlas vertebra, axis, craniovertebral junction, morphometry, bone screws

INTRODUCTION

The craniovertebral junction is a complex anatomical region formed by the occiput, atlas (C1), and axis (C2), and it has a critical role in supporting the skull while allowing flexion, extension, and axial rotation of the head⁽¹⁾. Surgical procedures in this region are technically demanding because C1 and C2 are closely related to the spinal cord, nerve roots, venous plexus, and vertebral artery⁽²⁾.

Posterior C1-C2 stabilization is widely used for atlantoaxial instability caused by trauma, congenital anomalies, inflammatory disease, degenerative disorders, and other craniovertebral junction pathologies⁽³⁾. Although modern screw fixation techniques provide strong biomechanical stability, inaccurate screw placement may result in serious neurovascular complications, particularly vertebral artery injury or spinal canal violation⁽⁴⁾.

The C1 has a unique ring-shaped structure without a vertebral body, and its posterior arch, lateral masses, superior and inferior articular facets, transverse foramina, and vertebral artery groove are important landmarks during screw fixation⁽⁵⁾. Previous cadaveric and radiological studies have emphasized that morphometric knowledge of the C1 posterior arch and lateral mass is essential for determining the feasibility, entry point, trajectory, and safe length of C1 screw placement⁽⁶⁾. Tan et al.⁽⁴⁾ evaluated screw fixation through the posterior arch and lateral mass of the C1 and showed that morphometric evaluation is necessary for assessing the feasibility of this technique. Similarly, cadaveric studies on atlantal lateral mass screws demonstrated that screw depth and trajectory vary according to the entry point and individual vertebral morphology⁽⁷⁾. The vertebral artery groove of the C1 is another clinically important structure because anatomical variations in this region may increase the risk of vascular injury during posterior

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exposure and screw insertion⁽⁸⁾. Morphometric studies of the C1 have reported clinically relevant measurements such as total C1 width, intertransverse foraminal distances, vertebral foramen dimensions, and vertebral artery groove thickness, all of which may guide safer surgical planning around C1⁽⁹⁾. Recent studies focusing on the lateral mass of the C1 have also shown that measurements such as inferior articular facet dimensions, screw length, horizontal thickness, vertical height, and screw trajectory angle may provide practical information for craniovertebral junction surgery⁽¹⁾.

The C2 is also surgically important because its dens, pedicles, pars interarticularis, laminae, vertebral canal, and articular facets are directly related to different fixation techniques⁽⁹⁾. C2 pedicle, pars, and laminar screw fixation require detailed anatomical knowledge because narrow pedicles, small laminar dimensions, or asymmetric bony structures may limit screw placement and increase the risk of cortical breach⁽¹⁰⁾. Morphometric studies of C2 have shown that pedicle width, pedicle height, laminar length, laminar thickness, vertebral canal dimensions, and dens measurements are important parameters for selecting the appropriate screw type and trajectory⁽¹¹⁾. Computed tomography (CT)-based and dry bone studies also suggest that C2 morphometric parameters may vary between populations, making population-specific anatomical data valuable for surgical planning⁽¹²⁾.

Although several studies have separately evaluated the morphometry of the C1 or C2, studies assessing C1 and C2 together on dry human bones remain limited⁽¹³⁾. Combined evaluation of C1 and C2 may provide a more comprehensive anatomical basis for craniovertebral junction surgery because stabilization procedures often involve both vertebrae⁽³⁾. Therefore, the present study aimed to perform a detailed morphometric analysis of dry human C1 and C2 vertebrae and to evaluate the potential implications of these measurements for safe C1-C2 screw placement.

MATERIALS AND METHODS

Study Design and Specimens

This study was designed as a descriptive osteometric anatomical study. A total of 35 dry human C1 vertebrae and 25 dry human C2 vertebrae were evaluated. All specimens were obtained from the anatomy laboratory collection. Only intact adult dry vertebrae with preserved anatomical landmarks were included in the study. Vertebrae with fractures, deformities, marked erosion, structural damage, or incomplete anatomical parts that could affect morphometric measurements were excluded. Representative dry human C1 and C2 vertebrae included in the study are shown in Figure 1. The anatomical figures were used to demonstrate the principal landmarks and the representative measurement approach. Because the morphometric parameters were obtained from different surfaces and orientations of the vertebrae, all measurement lines and abbreviations were not

displayed on a single figure in order to avoid overcrowding and preserve visual clarity.

Ethical Statement

The study protocol was approved by the Aydın Adnan Menderes University Faculty of Medicine Non-Interventional Clinical Research Ethics Committee (approval no: 2026/145, date: 05.05.2026). Informed consent was not required because the study was conducted on anonymized dry human vertebral specimens obtained from an anatomy laboratory collection and did not involve living participants or identifiable personal data.

Measurement Technique

All morphometric measurements were performed directly on dry bones using a digital caliper with 0.01 mm precision, as demonstrated in Figure 2. Measurements were recorded in millimeters. Right- and left-sided structures were measured



Figure 1. Representative dry human C1 and C2 vertebrae included in the study. C1: Atlas, C2: Axis



Figure 2. Measurement of C2 morphometric parameters using a digital caliper. C2: Axis

separately. Each measurement was performed twice, and the mean value was used for statistical analysis. The same anatomical landmarks were used consistently throughout the study to minimize measurement variability.

Representative photographs of the dry C1 and C2 vertebrae and the measurement technique were obtained. The images showing the use of the digital caliper were used to demonstrate the measurement method.

C1 Measurements

For the C1 vertebra, all measurements were obtained bilaterally where applicable using predefined anatomical landmarks. The main anatomical landmarks used for C1 morphometric measurements are illustrated in Figure 3. Vertebral canal length (VCL) represented the anteroposterior VCL, whereas vertebral canal width (VCW) represented the maximum transverse VCW. Outer distance of the vertebral artery groove (VAG-OD) and inner distance of the vertebral artery groove (VAG-ID) represented the VAG-OD and VAG-ID, respectively. Inferior articular facet length (IAF-L) and inferior articular facet width (IAF-W) represented the maximum IAF-L and IAF-W. Distance from the posterior arch to the anterior facet border (PA-AFB) represented the PA-AFB of the inferior articular facet. Horizontal thickness of the lateral mass (LM-HT) and vertical height of the lateral mass (LM-VH) represented the LM-HT and LM-VH, respectively. Superior articular facet anteroposterior length (SAF-APL) and superior articular facet width (SAF-W) represented the SAF-APL and SAF-W. Total C1 width (ATW) represented the maximum total transverse ATW, and vertebral foramen diameter (VF-D) represented the VF-D.

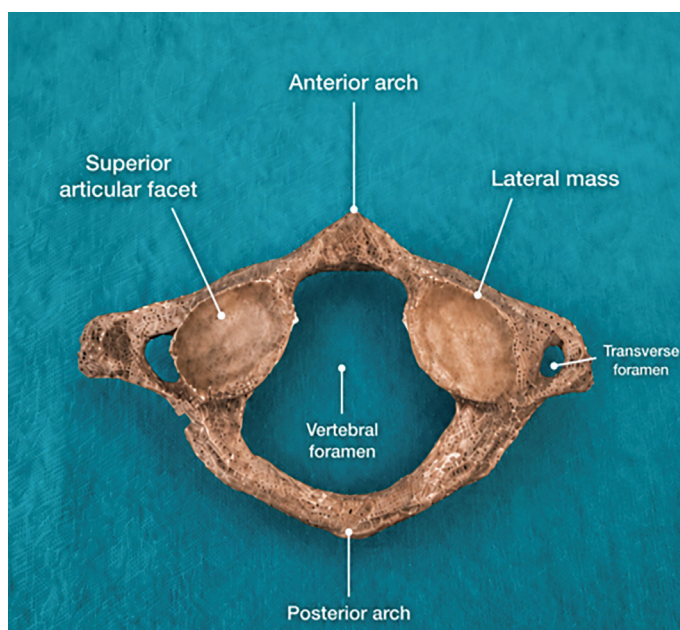


Figure 3. Representative dry atlas vertebra showing the anatomical landmarks used for morphometric measurements

C2 Measurements

For the C2 vertebra, all measurements were obtained bilaterally where applicable using predefined anatomical landmarks. Vertebral body anteroposterior diameter (VB-APD) represented the anteroposterior diameter of the vertebral body, vertebral body transverse diameter (VB-TD) represented the transverse diameter of the vertebral body, and vertebral body height (VB-H) represented the height of the vertebral body. Dens height (D-H), dens anteroposterior diameter (D-APD), and dens transverse diameter (D-TD) represented D-H, D-APD, and D-TD, respectively. Pedicle length (P-L), pedicle width (P-W), and pedicle height (P-H) represented P-L, P-W, and P-H, respectively. Lateral mass height (LM-H) and width (LM-W) represented LM-H and LM-W. Vertebral canal anteroposterior diameter (VC-APD) and vertebral canal transverse diameter (VC-TD) represented the VC-APD and VC-TD. Lamina length (LAM-L), Lamina thickness (LAM-T), and lamina height (LAM-H) represented LAM-L, LAM-T, and LAM-H, respectively. Superior articular facet diameter (SAF-D) and inferior articular facet diameter (IAF-D) represented the SAF-D and IAF-D.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Mac, version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean \pm standard deviation and minimum-maximum values. Right- and left-sided measurements were compared using the paired-samples t-test. A p-value of <0.05 was considered statistically significant. For midline or non-lateralized parameters, the same value was entered in both the right- and left-sided columns to maintain a consistent tabular format. Because these parameters do not represent true bilateral measurements, statistical comparison was not applicable. Accordingly, no test statistic was calculated for parameters with identical right- and left-sided values. This approach is consistent with the result tables already prepared for C1 and C2.

RESULTS

The right- and left-sided C1 morphometric measurements are summarized in Table 1. VAG-OD was significantly greater on the right side than on the left side (18.30 ± 2.72 mm vs. 15.54 ± 2.33 mm, $p < 0.001$). In contrast, VAG-ID was significantly greater on the left side (7.44 ± 1.48 mm vs. 8.53 ± 2.16 mm, $p = 0.006$). LM-HT was also significantly greater on the right side (12.74 ± 1.43 mm vs. 11.68 ± 2.16 mm, $p = 0.023$), whereas VF-D was significantly greater on the left side (6.63 ± 0.95 mm vs. 7.44 ± 0.95 mm, $p < 0.001$). No significant side-to-side differences were observed for IAF-L, IAF-W, LM-VH, SAF-APL, and SAF-W. For VCL, VCW, PA-AFB, and ATW, statistical comparison could not be performed because the right and left measurements were identical. The right- and left-sided C2 morphometric measurements are summarized in Table 2. Significant side-to-side differences were observed only in VC-APD and LAM-L. VC-APD was significantly

Table 1. Comparison of C1 measurements between right and left sides

Parameter	Right side	Left side	p-value
VCL	30.57±2.20 (26.80-36.70)	30.57±2.20 (26.80-36.70)	-
VCW	28.03±1.84 (24.50-31.50)	28.03±1.84 (24.50-31.50)	-
VAG-OD	18.30±2.72 (10.80-24.00)	15.54±2.33 (9.40-19.90)	<0.001
VAG-ID	7.44±1.48 (4.10-10.30)	8.53±2.16 (6.70-18.90)	0.006
IAF-L	17.45±1.36 (14.00-20.30)	17.64±0.96 (15.80-19.80)	0.543
IAF-W	14.38±1.40 (11.60-16.90)	13.96±1.06 (11.20-16.00)	0.114
PA-AFB	24.32±1.80 (21.10-27.60)	24.32±1.80 (21.10-27.60)	-
LM-HT	12.74±1.43 (9.60-15.50)	11.68±2.16 (7.50-20.50)	0.023
LM-VH	18.58±2.29 (12.20-22.60)	18.49±1.60 (15.20-22.50)	0.786
SAF-APL	21.77±3.42 (9.30-29.20)	21.98±1.62 (18.80-24.40)	0.684
SAF-W	10.40±1.52 (7.60-15.60)	9.93±1.70 (7.30-15.60)	0.153
ATW	71.30±6.45 (56.80-80.50)	71.30±6.45 (56.80-80.50)	-
VF-D	6.63±0.95 (4.70-8.80)	7.44±0.95 (5.70-9.50)	<0.001

Values are presented in millimeters as mean ± standard deviation (minimum-maximum). Right- and left-sided measurements were compared using the paired-samples t-test. A p-value of <0.05 was considered statistically significant. Parameters with identical right- and left-sided values represent midline or non-lateralized measurements; therefore, statistical comparison was not applicable for these variables. C1: Atlas, VCL: Vertebral canal length, VCW: Vertebral canal width, VAG-OD: Outer distance of the vertebral artery groove, VAG-ID: Inner distance of the vertebral artery groove, IAF-L: Inferior articular facet length, IAF-W: Inferior articular facet width, PA-AFB: Distance from the posterior arch to the anterior facet border, LM-HT: Horizontal thickness of the lateral mass, LM-VH: Vertical height of the lateral mass, SAF-APL: Superior articular facet anteroposterior length, SAF-W: Superior articular facet width, ATW: Total atlas width, VF-D: Vertebral foramen diameter

Table 2. Comparison of C2 measurements between right and left sides

Parameter	Right side	Left side	p-value
VB-APD	15.26±1.57 (13.10-18.70)	15.26±1.57 (13.10-18.70)	-
VB-TD	22.06±1.33 (19.00-24.20)	22.06±1.33 (19.00-24.20)	-
VB-H	19.86±1.92 (16.30-24.00)	19.86±1.92 (16.30-24.00)	-
D-H	16.05±2.07 (13.20-20.30)	16.05±2.07 (13.20-20.30)	-
D-APD	10.59±1.05 (8.90-12.60)	10.59±1.05 (8.90-12.60)	-
D-TD	9.86±1.02 (8.30-11.90)	9.86±1.02 (8.30-11.90)	-
P-L	27.27±1.78 (24.00-30.50)	27.46±2.42 (23.10-34.20)	0.631
P-W	8.18±1.14 (5.80-9.80)	8.30±1.16 (6.30-10.80)	0.675
P-H	8.27±1.21 (6.30-10.30)	8.52±1.24 (5.80-10.60)	0.387
LM-H	13.11±1.77 (9.90-16.70)	13.48±1.26 (11.10-16.60)	0.435
LM-W	10.95±1.41 (8.60-14.80)	10.97±1.80 (7.60-16.70)	0.955
VC-APD	5.80±0.93 (4.40-9.10)	5.24±0.81 (3.70-6.90)	0.025
VC-TD	5.44±0.63 (4.20-6.50)	5.59±1.10 (3.40-7.60)	0.533
LAM-L	21.20±2.15 (15.90-25.60)	20.02±2.25 (16.80-25.50)	0.027
LAM-T	6.18±1.33 (3.70-9.80)	6.04±1.15 (3.70-9.40)	0.461
LAM-H	11.40±1.79 (6.10-15.70)	11.22±1.47 (8.80-14.90)	0.341
SAF-D	17.32±1.66 (13.70-19.90)	17.61±1.45 (14.30-20.00)	0.456
IAF-D	11.01±1.38 (8.70-14.10)	11.48±1.50 (9.10-14.60)	0.143

Values are presented in millimeters as mean±standard deviation (minimum-maximum). Right- and left-sided measurements were compared using the paired-samples t-test. A p-value of <0.05 was considered statistically significant. Parameters with identical right- and left-sided values represent midline or non-lateralized measurements; therefore, statistical comparison was not applicable for these variables. C2: Axis, VB-APD: Vertebral body anteroposterior diameter, VB-TD: Vertebral body transverse diameter, VB-H: Vertebral body height, D-H: Dens height, D-APD: Dens anteroposterior diameter, D-TD: Dens transverse diameter, P-L: Pedicle length, P-W: Pedicle width, P-H: Pedicle height, LM-H: Lateral mass height, LM-W: Lateral mass width, VC-APD: Vertebral canal anteroposterior diameter, VC-TD: Vertebral canal transverse diameter, LAM-L: Lamina length, LAM-T: Lamina thickness, LAM-H: Lamina height, SAF-D: Superior articular facet diameter, IAF-D: Inferior articular facet diameter

greater on the right side than on the left side (5.80 ± 0.93 mm vs. 5.24 ± 0.81 mm, $p=0.025$). Similarly, LAM-L was significantly greater on the right side (21.20 ± 2.15 mm vs. 20.02 ± 2.25 mm, $p=0.027$). No significant differences were found for P-L, P-W, P-H, LM-H, LM-W, VC-TD, LAM-T, LAM-H, SAF-D, or IAF-D. For VB-APD, VB-TD, VB-H, D-H, D-APD, and D-TD, statistical comparison could not be performed because the right and left measurements were identical.

DISCUSSION

The present study evaluated the morphometric characteristics of dry human C1 and C2 vertebrae and demonstrated measurable side-to-side variations in selected C1 and C2 parameters. The main C1 findings were significant asymmetry in VAG-OD, VAG-ID, LM-HT, and VF-D, whereas the main C2 findings were significant right-sided predominance in VC-APD and LAM-L. These findings support the concept that even in apparently intact dry vertebrae, C1 and C2 morphology may show relevant bilateral differences that should be considered during craniovertebral junction surgery.

C1 lateral mass and vertebral artery-related measurements are particularly important because posterior C1-C2 fixation is performed in close proximity to the vertebral artery, venous plexus, C2 nerve root, and spinal canal. Saba et al.⁽¹⁾ emphasized that the C1 lateral mass is a key structure for screw fixation and that its morphometric dimensions can guide screw length, diameter, and trajectory planning in craniovertebral junction surgery. In the present study, VAG-OD was significantly greater on the right side than on the left side, while VAG-ID and VF-D were significantly greater on the left side. This asymmetric pattern suggests that vertebral artery groove-related anatomy and vertebral foramen dimensions may vary between sides, which may be surgically relevant during posterior exposure and instrumentation of C1. The close relationship between the vertebral artery and the posterior arch/lateral mass region of C1 has also been highlighted by Periyasamy et al.⁽¹³⁾, who described the vertebral artery groove as an important landmark after the artery exits the transverse foramen.

Although these side-to-side differences reached statistical significance, their clinical interpretation should be made cautiously. The absolute differences observed in several parameters were relatively small, and therefore they may not necessarily indicate a direct contraindication for screw placement. However, even small asymmetries in vertebral artery groove-related measurements, lateral mass dimensions, or lamina length may become relevant in borderline anatomical conditions, particularly when selecting the screw entry point, screw diameter, trajectory, and safe screw length. Therefore, the present findings should not be interpreted as replacing patient-specific preoperative CT evaluation, but rather as supporting the need for individualized and side-specific assessment before C1-C2 instrumentation.

The inferior articular facet measurements in the present study were generally comparable with those reported by Saba et al.⁽¹⁾. In their study, the length of the inferior articular facet was 17.93 ± 0.76 mm on the right side and 18.01 ± 0.75 mm on the left side, while the width was 14.88 ± 0.85 mm and 14.86 ± 0.79 mm, respectively⁽¹⁾. In the present study, the corresponding values were 17.45 ± 1.36 mm and 17.64 ± 0.96 mm for IAF-L, and 14.38 ± 1.40 mm and 13.96 ± 1.06 mm for IAF-W. These similarities indicate that the articular facet dimensions of the present sample are broadly consistent with previous dry C1 data. However, LM-HT was lower in the present study than in Saba et al.⁽¹⁾, who reported horizontal lateral mass thickness values of 15.91 ± 1.73 mm on the right and 15.83 ± 1.56 mm on the left. This difference may be related to population characteristics, sample size, or subtle differences in the exact anatomical landmarks used for measurement.

The PA-AFB measurement in the present study was 24.32 ± 1.80 mm on both sides, which was slightly higher than the values reported by Saba et al.⁽¹⁾. Saba et al.⁽¹⁾ reported the distance from the posterior arch of the C1 to the anterior margin of the inferior articular facet as 22.87 ± 0.60 mm on the right side and 22.79 ± 0.61 mm on the left side. Because this parameter is related to the potential screw path in posterior C1 lateral mass fixation, even small differences may be clinically relevant. Saba et al.⁽¹⁾ also noted that reported screw length recommendations vary across previous studies, supporting the need for individualized surgical planning rather than using a single universal value.

For C2, the present study found that most parameters did not show significant side-to-side differences, except for VC-APD and LAM-L. The right-sided LAM-L was significantly greater than the left-sided value, suggesting a degree of laminar asymmetry. This finding is partially consistent with Gosavi and Swamy⁽⁹⁾, who reported that C2 lamina length, thickness, and height were greater on the right side than on the left side and that these differences were statistically significant. In the present study, only lamina length reached statistical significance, whereas LAM-T and LAM-H were not significantly different. This discrepancy may reflect differences in sample size, population structure, or measurement technique.

The body and dens measurements of C2 in the present study were broadly close to those reported by Gosavi and Swamy⁽⁹⁾. In their dry bone study, the mean anteroposterior diameter of the C2 body was 14.77 ± 1.73 mm, the dens height was 14.86 ± 1.54 mm, and the average transverse diameter of the dens was 9.28 mm⁽⁹⁾. In the present study, VB-APD was 15.26 ± 1.57 mm, D-H was 16.05 ± 2.07 mm, and D-TD was 9.86 ± 1.02 mm. These findings suggest that the core morphometric dimensions of the C2 in the present sample are generally within the range of previous dry bone studies. However, VB-TD in the present study was higher than that reported by Gosavi and Swamy⁽⁹⁾, which may again be explained by anatomical variability or differences in measurement level. From a surgical perspective,

the statistically significant difference in lamina length may be relevant mainly for C2 translaminar screw planning, where lamina length and thickness influence screw trajectory and the available bony corridor. Nevertheless, the magnitude of this difference should be interpreted together with other morphometric parameters and individual CT anatomy rather than as an isolated determinant of screw feasibility.

Periyasamy et al.⁽¹³⁾ compared dry C1 and C2 bones with CT scan images and reported that several measurements differed significantly between the two methods. Their findings are important because they suggest that dry bone measurements and radiological measurements may not always be directly interchangeable. In the present study, all measurements were performed directly on dry bones, which provides precise osseous morphometry but does not account for soft tissue, cartilage, degenerative changes in living subjects, or radiological reconstruction factors. Therefore, the results may be most useful as anatomical reference data rather than as a substitute for patient-specific preoperative CT evaluation.

Thejeshwari et al.⁽¹⁴⁾ also emphasized the value of descriptive morphometric data of the C1 for neurosurgeons and orthopedic surgeons operating near the vertebral artery and nerve roots. Their study reported a mean C1 total width of 71.34 mm, which is very close to the ATW value of 71.30±6.45 mm in the present study⁽¹⁴⁾. This similarity supports the reliability of the present C1 width measurements. However, differences were observed in articular facet-related measurements between the present study and some previous reports, which may be due to regional anatomical variation, dry bone preservation status, and differences in landmark definitions.

The clinical relevance of the present study lies in its combined assessment of C1 and C2, because craniovertebral junction stabilization frequently requires instrumentation of both vertebrae. Morphometric evaluation of C1 is useful for lateral mass screw planning, whereas C2 measurements are important for pedicle, pars, and lamina screw placement. The significant asymmetries observed in C1 vertebral artery groove-related measurements and C2 lamina length support the need for side-specific assessment before instrumentation. These findings reinforce the importance of careful preoperative imaging and individualized screw trajectory planning.

Study Limitations

This study has some limitations. First, it was performed on dry bones, so demographic data such as age and sex were unavailable. Second, the sample size was modest, particularly for C2. Third, radiological correlation was not performed, and therefore the applicability of these measurements to CT-based surgical planning could not be directly tested. Finally, some measurements in previous studies were defined differently, which limits direct numerical comparison across studies. In addition, multiple morphometric parameters were statistically compared, and no adjustment for multiple comparisons was

applied. Therefore, statistically significant findings should be interpreted cautiously, particularly for parameters with relatively small absolute side-to-side differences.

CONCLUSION

In conclusion, the present study provides morphometric data on dry human C1 and C2 vertebrae and demonstrates significant side-to-side differences in selected parameters. At the C1 level, VAG-OD, VAG-ID, LM-HT, and VF-D showed significant asymmetry, while at the C2 level, VC-APD and LAM-L differed significantly between sides. These results may contribute to anatomical knowledge relevant to craniovertebral junction surgery and support the need for individualized, side-specific evaluation before C1-C2 screw placement.

Ethics

Ethics Committee Approval: The study protocol was approved by the Aydın Adnan Menderes University Faculty of Medicine Non-Interventional Clinical Research Ethics Committee (approval no: 2026/145, date: 05.05.2026).

Informed Consent: Informed consent was not required because the study was conducted on anonymized dry human vertebral specimens obtained from an anatomy laboratory collection and did not involve living participants or identifiable personal data.

Footnotes

Authorship Contributions

Surgical and Medical Practises: M.Ö.Y., I.A., M.Y.Ç., S.A., Concept: M.Ö.Y., Design: M.Ö.Y., I.A., Data Collection or Processing: M.Ö.Y., I.A., M.Y.Ç., S.A., Analysis or Interpretation: M.Ö.Y., I.A., M.Y.Ç., S.A., Literature Search: M.Ö.Y., Writing: M.Ö.Y., I.A.

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