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Investigation of Age-Related Changes of the Atlas for Posterior Cervical Screw Fixation Surgery: A Morphometric Computed Tomography Study

Serkan ONER[1], Rukiye Sumeyye BAKICI[2], Halide TEMELCI[3], Seyma TOY[2], Zulal ONER[3]

[1]Izmir Bakircay University, Faculty of Medicine, Department of Radiology, İzmir, Türkiye
[2]Karabuk University, Faculty of Medicine, Department of Anatomy, Karabuk, Türkiye
[3]Izmir Bakircay University, Faculty of Medicine, Department of Anatomy, İzmir, Türkiye

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Corresponding author: Zulal ONER ✉ zulal.oner@bakircay.edu.tr

ABSTRACT

AIM: To describe the morphometry of the atlas vertebrae regarding sex and age in posterior cervical surgery, provide a data source for surgery, and compare with other populations. In surgical operations, the morphology and morphometry of the atlas must be known.

MATERIAL and METHODS: Computed tomography images of 300 individuals aged 20–69 and referred to the hospital between 2020 and 2023 were used in retrospective research. The 14 parameters determined were examined in five groups formed by dividing ages into decades. The following parameters were measured: the transverse foramen area (TFA), length of the lateral mass (LLM), weight of the lateral mass (WLM), anteroposterior diameter of the left transverse foramen (ADTF), transverse diameter of the left transverse foramen (TDTF), posterior arch area (PAA), distance from the nearest point of the lateral mass on the posterior arch to the occipital condyle (OLM), posterior arch length (PAL), height of the lateral mass (HLM), and the height of the anterior tubercle of the atlas (HAT). In statistical analysis, the two-sample T-test, one-way ANOVA, and eta-squared (η^2) tests were used.

RESULTS: The HLM, WLM, PAA, PAL, OLM, HAT, TFA, ADTF, and TDTF were more considerable and statistically significant in males. It was statistically significant that the HAT and OLM were lower in the 2nd decade compared to other decades in females ($p<0.05$). In males, the LLM was smaller in the 3rd decade compared to individuals in the 2nd and 5th decades, which was statistically significant ($p<0.05$).

CONCLUSION: Based on the data presented, the present study will guide individuals in producing more appropriate screws (diameter, length) and safe surgical mediolateral angulation for the anatomical distinction between individuals' sexes and ages.

KEYWORDS: Atlas, Sex, Age, Lateral mass of atlas, Surgical technique

ABBREVIATIONS: CT: Computed tomography, **TFA:** Transverse foramen area, **LLM:** Length of lateral mass, **WLM:** Weight of lateral mass, **ADTF:** Anteroposterior diameter of left transverse foramen, **TDTF:** Transverse diameter of left transverse foramen, **NVF:** Nearest point of vertebral foramen, **FVF:** Furthest point of vertebral foramen, **PAA:** Posterior arch area, **OLM:** Distance from the nearest point of the lateral mass on the posterior arch to the occipital condyle, **PAL:** Posterior arch length, **HLM:** Height of lateral mass, **HAT:** Height of anterior tubercle of atlas, **HPT:** Height of posterior tubercle of atlas.

Serkan ONER : 0000-0002-7802-880X
Rukiye Sumeyye BAKICI : 0000-0001-8008-7174
Halide TEMELCI : 0000-0002-1314-6485
Seyma TOY : 0000-0002-6067-0087
Zulal ONER : 0000-0003-0459-1015

INTRODUCTION

The atlas (C1), categorized as an anatomically atypical vertebra with complex and variable constructions compared to other cervical vertebrae, is a crucial anatomical construction housing the bulbus and contains grooves for the C1 spinal nerve and vertebral levels (4,22). Instability or dislocation of the atlanto-occipital knuckle or C1-C2 complex may result from various sources, such as rheumatoid arthritis, broken C1-C2, ossa odontoidea, disruption of the transverse process ligaments, and tumor involvement in the surrounding area (22). Traumatization of the upper cervical spine can lead to weight-bearing instability, pain, neurological deficits, and death (28).

Posterior fixation using C1 pedicle screws and lateral mass is gaining acceptance among spine surgeons as the modality of choice for C1 instrumentation due to its preponderant biomechanical stability compared to other fixation modalities (16,22). However, proximity to important vascular and neural structures should be considered when using the fixation method. The ponticulus posticus (Kimmerle anomaly or arcuate foramen) may be confused with a wide posterior arch of the C1, while a lateral mass screw arrangement may provoke wounds to the vertebral artery (27). Additionally, a high-riding vertebral artery with a small pedicle is a substantial risk factor for a vertebral artery injury (16).

Determining the screw entry point before placing the screws is an essential detail for C1 fixation to prevent potentially fatal complications such as medulla spinalis and vertebral artery injury (28). Thus, the surgeon should have a detailed knowledge of the anatomy and morphometric features of the atlas.

Therefore, this study was designed to investigate changes in the atlas based on age for posterior cervical screw fixation surgery. Additionally, it aimed to obtain basic information about the anatomical parameters and dimensions of the atlas in developing innovative instruments.

MATERIAL and METHODS

The study was planned as a retrospective study, and approval was obtained from the Izmir Bakircay University Non-Interventional Ethics Board (Reference No: 1236 / Date:11.10.2023). Cervical computed tomography (CT) images were scanned between January 1, 2020, and October 10, 2023, in the Radiology Department of the University Hospital. Cervical CT images of 150 female and 150 male individuals aged between 20 and 69 were randomly selected in the study. Images of individuals with previous fractures in the cervical vertebrae resulting from trauma to the cranium or cervical region, a tumor, an infection, or previous surgery involving the cervical vertebrae were excluded from the study. Images with artifacts that impeded measurement were excluded from the study. During the measurements, the patients were categorized by sex and their initials were written in Excel, considering the personal data protection law.

Image Analysis

All measurements were made on the Horos (v3.3.06) workstation. The images were analyzed with two- and three-dimensional reconstructions in the standard bone screen, and the images focusing on the first cervical vertebra were positioned to the orthogonal plane in three planes (transverse, sagittal, and coronal). The images were then brought to the transverse and sagittal planes according to the parameters. Measurements were taken from the left half of the atlas only. They were performed by a radiologist (S.O.) with at least 15 years of experience, accompanied by two anatomists (PhD). Parameters were measured in the transverse and sagittal planes:

In the Transverse Plane

Transverse foramen shape (TFS): The shape of the transverse foramen was evaluated (1). It was classified as type 1 round, type 2 elliptical (anteroposterior), type 3 elliptical (transverse), type 4 kite, type 5 leaf, type 6 semicircle, or type 7 irregular.

Transverse foramen area (TFA): Transverse foramen area (Figure 1A).

Length of lateral mass (LLM): Straight length from the anterior to the posterior arch passing through the midpoint of the lateral mass of the atlas (Figure 1A).

Weight of lateral mass (WLM): Transverse width passing through the middle of the lateral mass of the atlas (Figure 1B).

Anteroposterior diameter of left transverse foramen (ADTF): The distance between the anterior and posterior points of the left transverse foramen (Figure 1C).

Transverse diameter of left transverse foramen (TDTF): The shortest distance from right to left of the left transverse foramen (Figure 1C).

Nearest point of vertebral foramen (NVF): The angle between the anterior tubercle of the atlas – the posterior tubercle of the atlas – and the transverse foramen (closest point to foramen vertebrae) (Figure 1D).

Furthest point of vertebral foramen (FVF): The angle between the anterior tubercle of the atlas – the posterior tubercle of the atlas – and the transverse foramen (farthest point to foramen vertebrae) (Figure 1E).

In the Sagittal Plane

Posterior arch area (PAA): Cross-sectional area of the posterior arch of the vertebral artery sulcus (Figure 2A).

The distance from the nearest point of the lateral mass on the posterior arch to the occipital condyle (OLM): The distance from the nearest point of the lateral mass on the posterior arch to the occipital condyle (Figure 2B).

Posterior arch length (PAL): Sagittal length of the posterior arch from the closest point to the lateral mass of the atlas (Figure 2B).

Height of lateral mass (HLM): The height of the middle of the lateral mass of the atlas (Figure 2C).

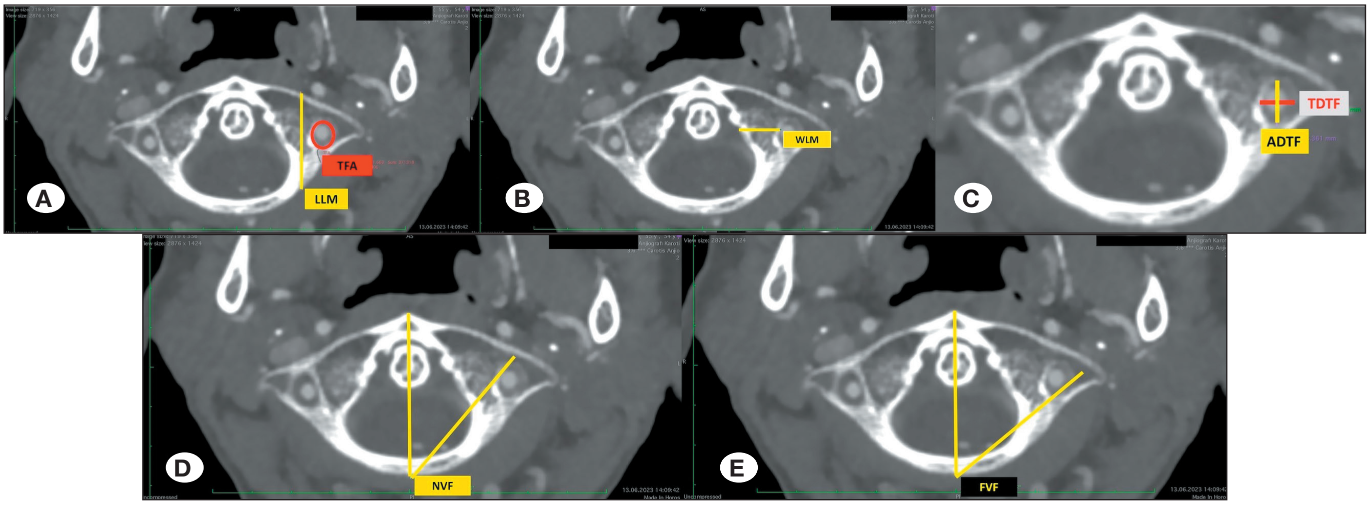

Figure 1: The horizontal plane measurements: **A) TFA:** transverse foramen area, **LLM:** length of lateral mass. **B) WLM:** weight of lateral mass. **C) ADTF:** anteroposterior diameter of left transverse foramen, **TDTF:** transverse diameter of left transverse foramen. **D) NVF:** nearest point of the vertebral foramen. **E) FVF:** furthest point of the vertebral foramen.

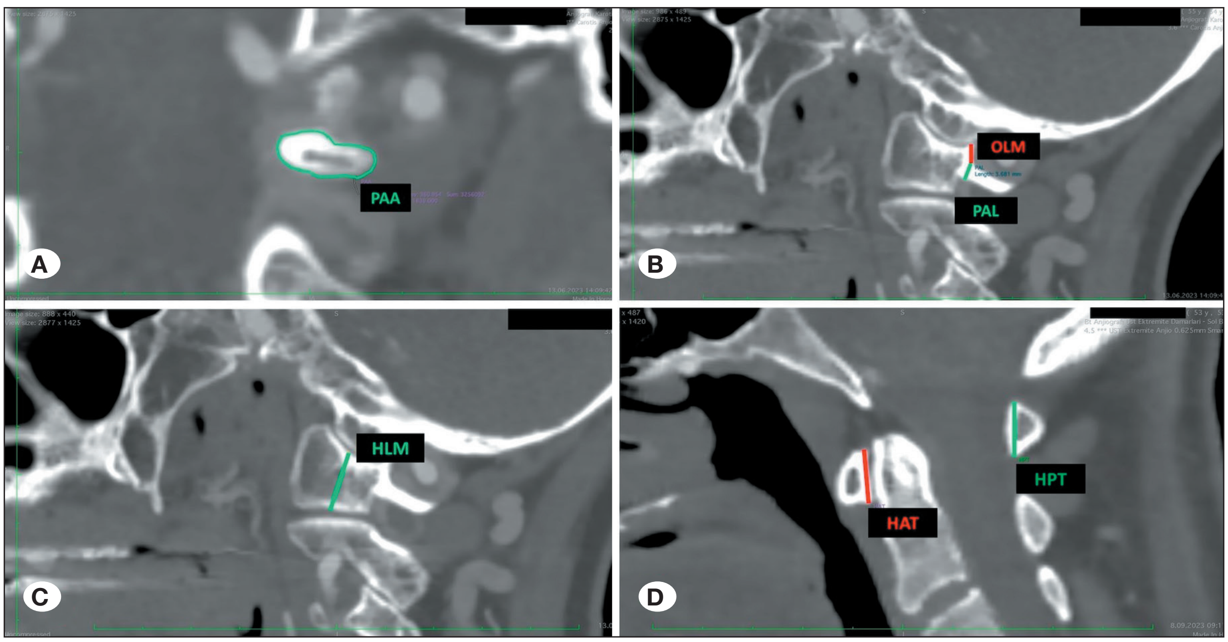

Figure 2: The sagittal plane measurements: **A) PAA:** Posterior arch area. **B) OLM:** Distance from the nearest point of the lateral mass on the posterior arch to the occipital condyle, **PAL:** Posterior arch length. **C) HLM:** Height of lateral mass. **D) HAT:** Height of anterior tubercle of atlas, **HPT:** height of posterior tubercle of atlas.

Height of anterior tubercle (HAT): The height at the midpoint of the anterior tubercle of the atlas (Figure 2C).

Height of posterior tubercle (HPT): The height of the atlas at the midpoint of the posterior tubercle (Figure 2D).

Statistical Analysis

Statistics were analyzed using IBM SPSS Statistics 22.0. Descriptive statistics (mean and standard deviation) were calculated for the parameters. The suitability of the measurement data for a normal distribution was judged with the Kolmogorov-Smirnov test. The two-sample T-test was used to determine the distribution based on sex. A one-way ANOVA test was used for the parameters suitable for a normal distribution when age was evaluated according to deciles. Post hoc, Tukey, and Tamhane's T2 tests were performed in pairwise comparisons. In parametric tests, eta-squared (η^2) calculations were performed to determine the degree of significant difference. Statistical significance was defined as a p-value below 0.05.

Power analysis: The calculated power (1-beta) based on this test is 1, considering a type I error (alpha) of 0.05, sample size of 300, effect size of 0.81, and a two-sided alternative hypothesis (H1).

Table I: Assessment of Measurements by Sex

Parameters	Male Mean±SD (CI)	Female Mean±SD (CI)	p-value[t]	η²
TFA (mm²)	46.6±10.0 (45.0-48.2)	41.6±8 (40.3-42.9)	**0.00***	0.69
ADTF (mm)	8.0±1.1 (7.8-8.2)	7.3±1.0 (7.1-7.5)	**0.00***	0.22
TDTF (mm)	7.5±1.1 (7.3-7.7)	6.5±0.9 (6.4-6.7)	**0.00***	0.27
WLM (mm)	15.2±1.5 (15.0-15.5)	12.9±1.3 (12.7-13.2)	**0.00***	0.47
LLM (mm)	29.3±16.3 (27.7-28.3)	27.4±2.0 (27.1-27.8)	0.16	-
PAA (mm²)	54.7±12.5 (52.7-56.7)	40.4±10.1 (38.8-42.0)	**0.00***	0.77
HLM (mm)	13.9±1.2 (13.7-14.1)	13.3±1.3 (13.1-13.5)	**0.00***	0.35
PAL (mm)	5.3±0.8 (5.2-5.5)	4.9±6.4 (4.8-5.0)	**0.00***	0.16
OLM (mm)	5.1±1.4 (4.9-5.3)	4.2±1.0 (4.1-4.4)	**0.00***	0.24
HAT (mm)	12.1±1.7 (11.8-12.3)	10.8±1.5 (10.6-11.1)	**0.00***	0.34
HPT (mm)	11.0±1.7 (10.7-11.3)	10.2±6.7 (9.1-11.3)	0.19	-
NVF (°)	38.15±3.27 (37.6-38.6)	37.52±3.22 (37.0-38.0)	0.09	-
FVF (°)	48.33±3.42 (47.7-48.8)	47.76±3.38 (47.2-48.3)	0.15	-

p<0.001, **t: Two-sample T test, **η²:** eta-squared, **SD:** Standard Deviation, **CI:** 95% Confidence Interval for Mean, **TFA:** Transverse foramen area, **ADTF:** Anteroposterior diameter of left transverse foramen, **TDTF:** Transverse diameter of left transverse foramen, **WLM:** Weight of lateral mass, **LLM:** Length lateral Mass, **PAA:** Posterior arch area, **HLM:** Height of lateral mass, **PAL:** Posterior arch length, **OLM:** Distance from the nearest point of the lateral mass on the posterior arch to the occipital condyle, **HAT:** Height of anterior tubercle of atlas, **HPT:** Height of posterior tubercle of atlas, **NVF:** Nearest point of vertebral foramen, **FVF:** Furthest point of vertebral foramen.*

RESULTS

A total of 300 individuals, 150 females and 150 males, were included in the study. Individuals aged between 20 and 69 were then divided into five groups, with 30 females and 30 males in every decade. The average age was 44.48 ± 14.66 for females and 44.32 ± 14.41 for males. When examining the ages of the individuals according to sex, no significant difference was detected (p>0.05).

The TFA, ADTF, TDTF, WLM, PAA, HLM, PAL, OLM, and HAT parameters were higher in males, which was statistically significant (p<0.05). The LLM, HPT, NVF, and FVF measurements were higher in males, but the gap was not statistically significant (p>0.05). Considering the size effect, it was believed that the variance observed from the morphometric measurements of the C1 vertebra was sex-dependent, with the highest rate of 77% for the PAA, followed by 69% for the TFA, and the lowest rate of 16% for the PAL (Table I). Figure 3 presents the distinction of the TFS based on sex.

No statistically significant difference was found between age groups for the TFA, ADTF, TDTF, WLM, LLM, PAA, HLM, PAL, HPT, NVF, or FVF parameters in females (p>0.05). The OLM and HAT measurements were smaller in individuals in the 2nd decade than in those in other decades. This difference was determined as statistically significant (p>0.05; Table II). Considering the effect size, it was believed that the variances observed in the decades originating from morphometric measurements of the C1 vertebra in females were age-dependent at rates of 36.7% for the HAT parameter and 41.1% for the OLM.

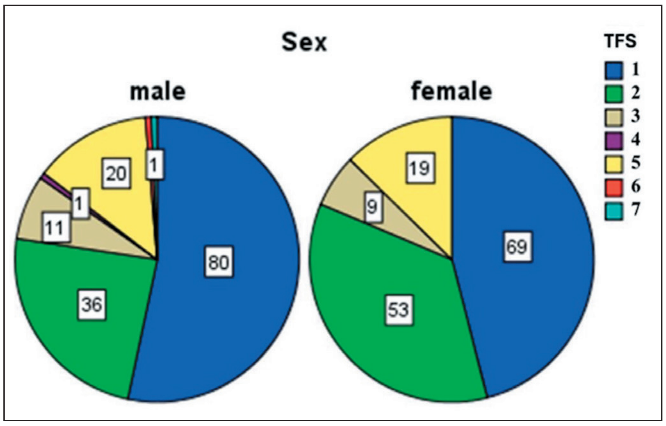

Figure 3: Distribution of transverse foramen shapes by sex.

In males, it was determined that the differences between the age groups for the TFA, ADTF, TDTF, WLM, PAA, HLM, PAL, OLM, HPT, NVF, and FVF were not statistically significant (p>0.05). The LLM measurement was smaller in individuals in the 3rd decade than in those in the 2nd and 5th decades. The HAT was smaller for individuals in the 2nd decade than those in the 4th, 5th, and 6th decades, and smaller for individuals in the 3rd decade than those in the 6th decade ($p<0.05$; Table III). Considering the effect size, it was believed that the variances between decades originating from morphometric measurements of the C1 vertebra in males were age-dependent at a rate of 32.5% for the HAT and 51.5% for the OLM.

DISCUSSION

Advances in technology and experience have shown that screw fixation is preferred over cabling techniques (8). The C1 posterior arch screw technique is becoming a favored option, especially for short-segment cervical fixation and C1 rigid stable fixation (29). In cases where occipitocervical fusion is required, such as atlanto-occipital dislocation treatment (for conditions causing significant morbidity and mortality), a lateral mass screw could be used at C1 (21). Serious complications such as surgical area infection, neurological and vascular injuries, screw fracture, and bone nonunion may occur in cervical region surgery (19,20). Age-related atlas changes in adults are important because this is the first study aiming to provide a radio-anatomical basis for posterior screw fixation surgery. The results of this study will be valuable in preventing neurovascular injury and pedicle fractures due to the selection of a large screw during C1 laminar screw fixation.

In our study, the mean LLM was 27.4 ± 2.0 mm in females and 29.3 ± 16.3 mm in males, and the location of the transverse foramen was between 38° and 48° in males and 37° and 47° in females based on age group. Safe deviation angles vary significantly by sex. No previous study was found that exam-

Table II: Measurement Results for the Parameters Examined by Dividing Ages into Decades in Females

Parameters	2nd Decade Mean±SD (Min-Max)	3rd Decade Mean±SD (Min-Max)	4th Decade Mean±SD (Min-Max)	5th Decade Mean±SD (Min-Max)	6th Decade Mean±SD (Min-Max)	p-value
TFA (mm^2)	39.2±8.7 (25.4-62.6)	40.1±7.5 (25.0-58.0)	43.0±7.7 (29.0-60.2)	42.8±8.5 (30.1-56.9)	43.0±8.1 (24.5-57.2)	0.20
ADTF (mm)	7.0±1.2 (4.5-9.9)	7.3±0.8 (5.7-9.5)	7.3±0.9 (6.0-9.5)	7.4±1.0 (5.8-9.7)	7.5±0.9 (5.9-9.8)	0.28
TDTF (mm)	6.7±0.9 (5.0-9.7)	6.4±0.8 (4.3-8.2)	6.6±0.8 (4.6-8.4)	6.4±0.9 (4.9-8.8)	6.5±0.9 (4.5-8.4)	0.63
WLM (mm)	12.9±1.6 (8.7-16.3)	13.0±1.3 (9.6-15.6)	12.7±1.3 (10.8-16.4)	13.0±1.1 (10.6-15.1)	13.1±1.5 (9.5-15.5)	0.91
LLM (mm)	27.7±2.6 (20.7-31.5)	26.9±1.8 (22.9-29.4)	27.7±1.7 (23.9-31.4)	27.3±1.9 (22.6-33.0)	27.4±2.0 (20.7-31.8)	0.47
PAA (mm^2)	36.3±10.8 (22.3-65.3)	40.7±8.2 (27.8-56.1)	42.0±9.5 (22.0-58.1)	41.7±10.0 (20.1-64.2)	41.3±11.2 (20.4-63.9)	0.16
HLM (mm)	13.1±1.1 (11.4-15.7)	13.7±1.6 (11.1-18.2)	13.3±1.3 (10.8-16.5)	13.2±1.1 (11.4-15.9)	13.1±1.4 (10.5-16.8)	0.33
PAL (mm)	4.8±0.7 (3.5-6.5)	5.0±0.6 (3.7-6.3)	4.8±0.5 (3.8-5.9)	5.0±0.5 (4.0-6.1)	4.9±0.7 (3.5-6.7)	0.62
OLM (mm)	3.4±1.3 (1.2-7.5)	4.7±0.9 (2.1-6.0)	4.4±0.8 (2.4-6.1)	4.4±0.8 (2.0-5.9)	4.3±0.9 (1.8-6.2)	**0.00***
HAT (mm)	9.7±1.2 (7.1-13.3)	10.9±1.3 (8.4-14.6)	11.2±1.1 (9.1-13.0)	11.0±1.5 (8.7-15.0)	11.3±1.9 (8.9-16.3)	**0.00***
HPT (mm)	9.7±2.0 (6.4-14.0)	9.7±1.2 (8.1-12.8)	9.2±1.5 (6.9-12.0)	12.6±14.7 (6.8-90.0)	9.9±1.4 (6.7-12.9)	0.31
NVF (°)	37.94±3.39 (32.66-48.05)	37.68±2.93 (31.62-44.69)	36.38±3.47 (28.09-45.26)	38.05±2.98 (33.11-45.77)	37.56±3.21 (29.66-48.05)	0.27
FVF (°)	47.88±3.92 (41.73-59.78)	47.59±3.13 (42.24-54.51)	47.20±3.37 (38.54-55.02)	48.18±3.13 (43.85-55.38)	47.76±3.38 (38.54-59.78)	0.82

p<0.001, SD:** *Standard deviation,* ***TFA: *Transverse foramen area,* ***ADTF:*** *Anteroposterior diameter of left transverse foramen,* ***TDTF:*** *Transverse diameter of left transverse foramen,* ***WLM:*** *Weight of lateral mass,* ***LLM:*** *Length lateral mass,* ***PAA:*** *Posterior arch area,* ***HLM:*** *Height of lateral mass,* ***PAL:*** *Posterior arch length,* ***OLM:*** *Distance from the nearest point of the lateral mass on the posterior arch to the occipital condyle,* ***HAT:*** *Height of anterior tubercle of atlas,* ***HPT:*** *Height of posterior tubercle of atlas,* ***NVF:*** *Nearest point of vertebral foramen,* ***FVF:*** *Furthest point of vertebral foramen.*

Table III: Measurement Results for the Parameters Examined by Dividing Age into Decades in Males

Parameters	2nd Decade Mean±SD (Min-Max)	3rd Decade Mean±SD (Min-Max)	4th Decade Mean±SD (Min-Max)	5th Decade Mean±SD (Min-Max)	6th Decade Mean±SD (Min-Max)	p-value
TFA (mm^2)	46.8±11.0 (31.8-76.0)	49.4±11.3 (24.8-86.9)	44.8±9.2 (27.8-65.5)	46.8±10.1 (31.1-72.0)	45.2±8.0 (30.0-62.2)	0.42
ADTF (mm)	7.6±1.1 (5.7-11.2)	8.2±1.1 (6.1-11.9)	7.9±1.0 (6.4-10.6)	8.2±1.2 (6.2-10.5)	7.9±1.0 (6.0-9.6)	0.26
TDTF (mm)	7.9±1.2 (6.3-11.0)	7.7±1.2 (5.2-9.7)	7.3±1.1 (5.3-10.0)	7.3±0.9 (6.0-10.0)	7.3±0.9 (6.0-9.8)	0.12
WLM (mm)	15.0±1.8 (11.5-18.6)	14.7±1.4 (1.7-17.0)	15.4±1.4 (11.9-18.1)	15.5±1.4 (11.9-18.1)	15.5±1.6 (11.8-20.0)	0.21
LLM (mm)	28.6±2.0 (23.3-32.3)	27.0±2.1 (22.0-30.9)	28.2±2.0 (23.5-31.4)	28.5±1.7 (23.8-32.5)	27.8±1.8 (23.3-30.4)	**0.01***
PAA (mm^2)	52.1±12.8 (31.1-94.3)	54.4±11.9 (30.9-97.1)	56.4±10.3 (40.8-92.1)	57.2±12.9 (34.9-85.9)	53.5±14.4 (27.2-92.4)	0.50
HLM (mm)	14.0±1.0 (11.5-16.2)	13.6±1.5 (10.2-16.2)	13.8±1.1 (10.3-16.0)	14.2±1.2 (11.5-16.7)	13.8±0.9 (10.9-15.2)	0.30
PAL (mm)	5.5±0.8 (3.5-7.5)	5.2±0.8 (4.0-7.4)	5.3±0.6 (3.8-6.9)	5.5±0.8 (3.1-6.9)	5.2±0.8 (4.2-7.4)	0.51
OLM (mm)	5.2±1.1 (2.5-7.7)	5.1±0.9 (3.8-7.2	5.0±1.0 (2.5-7.2)	5.0±0.7 (3.2-6.7)	5.0±1.5 (2.0-7.8)	0.98
HAT (mm)	10.8±1.1 (9.1-14.3)	11.6±1.4 (8.5-15.3)	12.5±1.7 (10.1-16.4)	12.5±1.8 (8.8-17.6)	12.9±1.5 (10.0-16.1)	**0.00***
HPT (mm)	10.9±1.8 (7.3-14.4)	10.8±1.6 (6.3-13.5)	11.2±1.4 (7.7-14.6)	11.3±2.2 (7.8-16.4)	10.7±1.7 (7.6-14.9)	0.62
NVF (°)	38.75±3.31 (32.87-46.57)	37.92±4.11 (30.01-47.56)	38.13±3.03 (31.37-43.68)	37.60±3.06 (32.54-45.24)	38.38±2.76 (31.92-44.59)	0.70
FVF (°)	48.67±3.25 (44.16-56.79)	48.47±3.89 (37.21-56.22)	48.25±3.09 (42.17-56.22)	47.85±3.69 (40.68-58.57)	48.42±3.29 (42.38-56.40)	0.91

p<0.05, **SD: Standard deviation, **TFA:** Transverse foramen area, **ADTF:** Anteroposterior diameter of left transverse foramen, **TDTF:** Transverse diameter of left transverse foramen, **WLM:** Weight of lateral mass, **LLM:** Length lateral mass, **PAA:** Posterior arch area, **HLM:** Height of lateral mass, **PAL:** posterior arch length, **OLM:** Distance from the nearest point of the lateral mass on the posterior arch to the occipital condyle, **HAT:** height of anterior tubercle of atlas, **HPT:** Height of posterior tubercle of atlas, **NVF:** Nearest point of vertebral foramen, **FVF:** Furthest point of vertebral foramen.*

ined the morphometry of the atlas in adult individuals over decades. This study is the first to provide a safe surgical area according to age in surgical interventions performed from the posterior aspect of the atlas.

A study of 135 atlases in the Egyptian population reported that FTS was observed in four different types, and the most dominant was type 1 (round) (2). In another study, the most common type of C1 was elliptical (1). In this study, FTS was observed in seven different ways in 300 CT scans. Type 1 was the most dominant in males and females. FTS was found in more diverse forms in males. We believe the differences between the studies are due to the number of individuals and population differences.

In this study, the TFA was higher in males at 46.6 mm^2; it was 41.6 mm^2 in females. Studies report that this parameter is significantly higher in males than in females (7,23).

A study explained that the ADTF was significantly higher in males than in females, and the TDTF did not differ significantly between sexes (7). Another study reported that the ADTF was 6.7 ± 1.0 mm in females and 7.1 ± 1.0 mm in males; the TDTF was 5.5 ± 0.8 mm in females and 5.9 ± 0.9 mm in males. Moreover, the differences were significant (23). This study found that the average ADTF was 7.3 ± 1.0 mm in females and 8.0 ± 1.1 mm in males; the average TDTF was 6.5 ± 0.9 mm in females and 7.5 ± 1.1 mm in males. These results were consistent with those of other studies.

In this study, the mean WLM was 12.9 ± 1.3 mm in females and 15.2 ± 1.5 mm in males. No directional difference was explained in an atlas study conducting bilateral evaluation (25). Lenz et al. reported that the was lower in females than in males, similar to our study (17).

In this study, the mean LLM was greater in males (29.3 ± 16.3 mm) than in females (27.4 ± 2.0 mm). In a study conducted on Asian individuals, the mean LLM on the left was reported as 30.07 ± 1.66 mm (25), and in Thai individuals, the ideal left screw length was stated as 28.59 ± 1.93 mm (28). The effective screw length for Asian individuals in China was defined as 21.87 mm (11), and in the Portuguese population, it was reported as 27.69 ± 2.09 mm (n=26) in males and 26.50 ± 2.09 mm (n=24) in females (19). A study conducted in the Asian population estimated the screw length as between 23.2 and 30.2 mm (16). In a study conducted in Austria, the length of the screw passing through the lateral mass was 30.1 ± 2.1 mm (n=50) on the left (15). Another study conducted in Germany reported that the LLM was higher in males (17). When examining these studies, it was observed that the screw length used in posterior cervical surgeries was between 21 and 31 mm. In posterior cervical fixation to C1, care should be taken regarding the screw used, especially in the Harms technique (9,28). The millimetric differences between studies may be due to the population differences.

This study's cross-sectional area of the PAA was 54.7 mm^2 in males and 40.4 mm^2 in females. Since this parameter differs by sex, we believe attention should be paid to the screw used in surgery. In the studies examined, this region was not evaluated by sex; only the average area (55.02 ± 18.51 mm^2) (26), height (17), and width (6) measurements were given. The HLMs in this study were greater in males (13.9 ± 1.2 mm) than in females (13.3 ± 1.3 mm). Another study found that only directions were considered and not sex (25). Therefore, PAA and HLM measurements could not be compared with other studies. The HLM should be considered for the screw diameter in surgical operations performed on type 1 and 3 Jefferson fractures. Additionally, the length of this parameter should be considered for the C1 lateral mass screws applied for the Goel-Harms technique (10) and Magerl technique (18).

In a study in Thailand, the left PAL was reported as 4.4 mm in females and 4.8 mm in males (28), and the average length in another study of pediatric individuals was 7.0 ± 1.5 mm (range 4.2–11.8 mm) (12). The height of the leanest part of the left vertebral artery groove in Japanese cadavers was determined as 4.30 ± 0.95 mm (14). Another study reported this parameter as 5.39 ± 1.58 mm on average (25). The mean PAL in this study was 4.9 ± 6.4 mm in females and 5.3 ± 0.8 mm in males. Similarly, a study conducted with Korean cadavers found that this parameter was greater in males (13). When examining studies on posterior cervical screw fixation surgery, it was observed that the screw diameter used in surgeries performed based on this parameter was 3.5 mm (4), or 3.8, 4.2, 4.5, or 5.5 mm (5, 16). The differences among studies evaluating sex may be due to population differences.

The mean OLM in our study was greater in males (5.1 ± 1.4 mm) than in females (4.2 ± 1.0 mm). Among the literature studies reviewed, none were found that evaluated this parameter. Thus, this parameter is original. The average HAT in this study was longer in males (12.1 ± 1.7 mm) than in females (10.8 ± 1.5 mm). The HPT did not differ between males (11.0 ± 1.7 mm) and females (10.2 ± 6.7 mm). Of the literature studies reviewed, none were found evaluating the HAT and HPT according to sex.

No difference was found in NVF and FVF angle measurements by sex for determining the transverse foramen localization. The transverse foramen is located between 28° and 59° in females and 30° and 58° in males. One study stated that the straight screw direction was safe for entry into C1, but a medial angulation of up to 20° could be performed (3). In another study measuring the lateralization angle, the mean value was 10.79 ± 2.45° (28). In an atlas study, a partial radiological safety zone was defined between 19.6° medial and 11.6° lateral from an idealized entry point located 22.8 mm away (17). We believe the angle difference is due to the different reference points.

No differences were found between age groups in males and females in the TFA, ADTF, TDTF, WLM, PAA, HLM, PAL, HPT, NVF, or FVF. However, it was found that the OLM and HAT were minor in females in the 2nd decade of life compared to the other decades. Therefore, we recommend exercising more caution in surgical operations performed on females aged under 30. The LLM in males was lower in individuals in the 3rd decade than in those in the 2nd and 5th decades. Therefore, this parameter, which could be used for screw length, must be handled cautiously due to the difference in age groups in males.

In the study, males in the 2nd decade had smaller HATs than those in the 4th, 5th, and 6th decades, and those in the 3rd decade had smaller HATs than those in the 6th decade. The smallest two age groups for the HAT and HPT parameters in a pediatric study were reported as significantly smaller than the other groups (24). Children aged 4–18 in another pediatric study were divided into five groups 3 years apart. Consequently, a significant difference was found among the HPT groups except for the 7–9 and 10–12 age groups (12). Thus, we believe age groups should be considered when performing surgical operations. Although the current study is morphological, the findings may have potential clinical implications in surgical procedures involving the atlas, particularly in minimizing complications and improving surgical outcomes. Future studies could explore the relationship between morphological variations and clinical outcomes in a surgical context.

A limitation of this study is that the data were obtained from a single medical center and only reflect the characteristics of the local population. Future studies should include and examine a more diverse sample from different regions to reveal additional variations and explore their implications for cervical surgery more comprehensively.

CONCLUSION

Based on the results of this study, it was concluded that a maximum lateral angulation of 28° in females and 30° in males

(NVF-FVF) is safe in posterior cervical screw fixation surgery. The screw length (LLM) was between 20 and 33 mm in females and 22 and 32 mm in males. As the PAL is a fragile parameter, attention should be paid to the screw diameter regarding gender and age. If a 3.5 mm diameter screw is used in operations, it may be unsuitable for individuals with a PAL below 3.5 mm and may cause surgical complications. Therefore, the measurements in our study can reduce the use of intraoperative fluoroscopy by providing more appropriate screw selection in occipitocervical stabilization surgery, especially in screw surgery to the atlas. In cases where screw placement is required in the lateral mass of the atlas, this study could be taken as a guide regarding age groups. The results of this study concerning individuals without variations in the atlas may support surgeons in preoperative evaluation. However, these results should not be considered regarding ponticulus posterior, lateral ponticulus, or vertebral artery variations not located in the vertebral artery groove. Preoperative CT should be undertaken under such conditions. Additionally, this will facilitate a specific approach, as it provides information about the distances for surgery in the parameters of the transverse foramen and the vertebral artery groove through which the vertebral artery passes. We believe these detailed data will help spine surgeons achieve safe and effective screw placement.

Declarations

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AUTHORSHIP CONTRIBUTION

Study conception and design: SO, ZO

Data collection: SO, HT

Analysis and interpretation of results: SO, RSB

Draft manuscript preparation: SO, HT, RSB

Critical revision of the article: SO, ZO, ST

Other (study supervision, fundings, materials, etc...): SO, ZO, RSB, HT, ST

All authors (SO, RSB, HT, ST, ZO) reviewed the results and approved the final version of the manuscript.

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