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Original Article

Morphometric and Morphological Evaluation of the Atlas: Anatomic Study and Clinical Implications

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ABSTRACT

Objective: Atlas is located at a critical point close to the vital centers of the medulla oblongata, which can be compressed by the dislocation of the atlantoaxial complex or instability of the atlantooccipital joint. This study aimed to determine in detail the morphometric and morphological characteristics of the atlas to guide the reduction of the risk of complications and increase the success rate in various surgical approaches for the craniovertebral junction.

Methods: In this study, 17 atlas vertebrae whose measurement parameters were pronounced and unknown gender, age, and ethnic characteristics were examined.

Results: Totally 16 parameters, 11 of which were bilateral and 5 were unilateral, were examined on the atlas. Also, no accessory foramen transversarium was found in these atlas vertebrae. Of the 23 foramina transversaria that were prominent and not broken, 7 were found to be round-shaped (30.43%), and 16 were oval-shaped (69.57%).

Conclusion: It is deducted that the results obtained in this study will help to have information about the morphometry and morphology of atlas vertebrae. Although information such as age, gender, and ethnic origin is not known about the bones evaluated, it is the advantage of this study that a large number of parameters are evaluated and compared with previous publications. Nevertheless, it seems that there is a need for studies in which much more cases are assessed, and information such as age, gender, and ethnic origin is known.

Keywords: Atlas, craniovertebral junction, dry bone, morphometry, morphology

INTRODUCTION

Craniovertebral junction (CVJ) surgery is one of the essential parts of spinal surgery.[1] The CVJ is an anatomical transition zone between the skull and the cervical spine. It contains the caudal part of the occipital bone, atlas and axis vertebrae, ligaments, many cranial nerves, blood vessels, and lymphatics.[2,3] Atlas vertebrae within the CVJ have anatomical properties that differ from other cervical vertebrae.[4] In CVJ surgery, it is necessary to have knowledge about the anatomy of this region, particularly the atlas vertebrae.[1] Cacciola et al[5] stated that the anatomy of the vertebral artery at the level of atlas and axis vertebrae is significantly different from the relatively straightforward course of the C3 to C6 vertebrae. Due to these anatomical differences and the location of the vertebral artery groove in a vital place, surgical procedures in this region are very difficult.[1] However, the number, size, and shape of the foramen transversarium can affect the morphology of the vertebral artery. Besides, conditions such as vertebrobasilar insufficiency, headache, migraine, and fainting attacks may occur as a result of pressure on the vertebral artery due to these variations.[6]

Atlas has a joint relationship with the occipital bone and axis.[1] Also, the atlas is located at a critical point close to the vital centers of the medulla oblongata, which can be compressed by the dislocation of the atlantoaxial complex or instability of the atlantooccipital joint.[7] Besides, the placement of the pedicle screw can damage essential structures such as the spinal cord, nerve roots, cranial nerves, and vertebral arteries.[4] Moreover, as different methods developed for the treatment of pathologies of this region, the bone structure's anatomy should be better known.[8] Cacciola et al[5] stated that understanding the atlas is crucially essential for any surgery in the CVJ.

This study aimed to determine in detail the morphometric and morphological characteristics of the atlas to guide the reduction of the risk of complications and increase the success rate in various surgical approaches for the CVJ.

METHODS

In this study, 17 atlas vertebrae whose measurement parameters were pronounced and unknown gender, age, and ethnic

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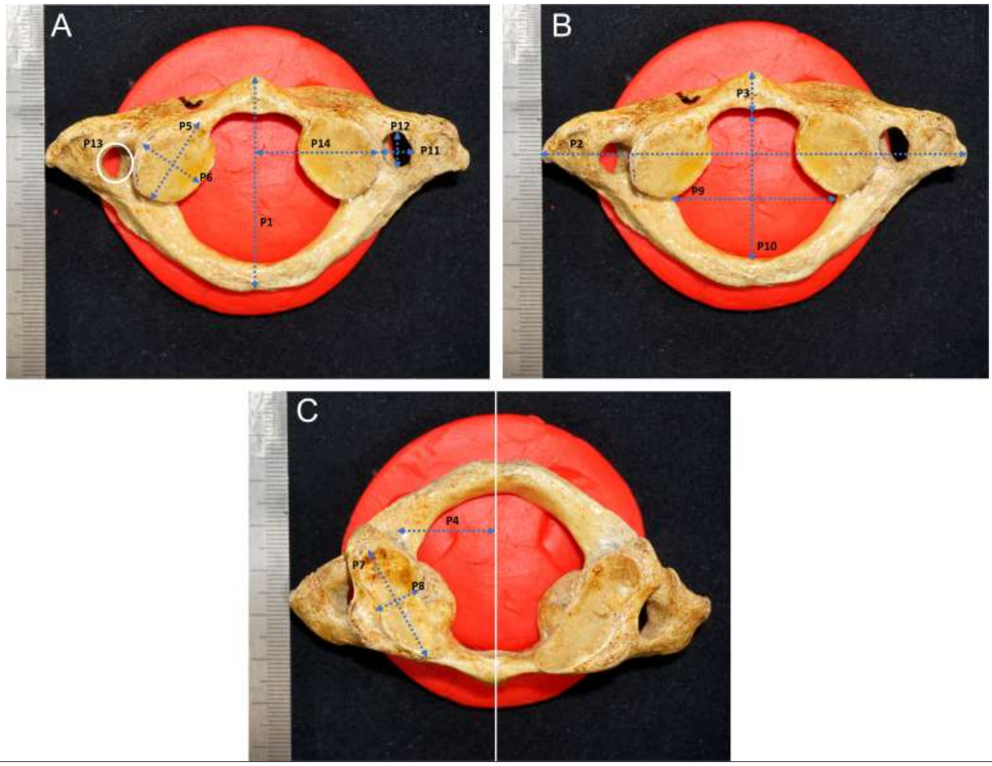
Figure 1. A-C. Inferior (A, B) and superior (C) views of the atlas.



characteristics in the Department of Anatomy of Gaziantep University Faculty of Medicine were examined. Playdough was used to keep the bones in position. Photos of the bones were taken from the top, front, and lateral sides with the Sony Nex 6 camera, Canon 50 mm, and 35 mm macro lenses. A ruler was placed next to the bones to ensure standardization and calibration while measuring on the photograph. To achieve better image quality, a mechanism that distributes the light evenly was used. The following 16 parameters, 11 of which (P4, P5, P6, P7, P8, P11, P12, P13, P14, P15, and P16) were bilateral and 5 (P1, P2, P3, P9, and P10) were unilateral, were examined on the atlas (Figure 1 A-C). The first 14 of them were carried out on the photograph of the bones using ImageJ 1.50 software. Also, the shape of the foramen transversarium (P15) and the presence of the accessory foramen transversarium (P16) were morphologically evaluated.

Main Points

- Atlas is located at a critical point close to the vital centers of the medulla oblongata, which can be compressed by the dislocation of the atlantoaxial complex or instability of the atlantooccipital joint.
- It is deducted that the results obtained in this study will help to have information about the morphometry and morphology of atlas vertebrae.
- Although information such as age, gender, and ethnic origin is not known about the bones evaluated, it is the advantage of this study that a large number of parameters are evaluated and compared with previous publications.
- Nevertheless, it seems that there is a need for studies in which much more cases are assessed, and information such as age, gender, and ethnic origin is known.

P1: Length of the atlas

P2: Width of the atlas

P3: Anteroposterior thickness of the anterior arch of atlas

P4: Distance between midline and groove for vertebral artery

P5: Anteroposterior diameter of inferior articular facet

P6: Transverse diameter of inferior articular facet

P7: Anteroposterior diameter of superior articular facet

P8: Transverse diameter of superior articular facet

P9: Transverse diameter of vertebral foramen

P10: Sagittal diameter of vertebral foramen

P11: Transverse diameter of foramen transversarium

P12: Anteroposterior diameter of foramen transversarium

P13: Area of foramen transversarium

P14: The distance between the most medial point of the foramen transversarium and the midline

P15: Shape of the foramen transversarium

P16: Presence of the accessory foramen transversarium

Statistical Analysis

Descriptive statistics were evaluated for the morphometric measurements, and their statistical distribution was analyzed. Shapiro–Wilk test was used for normality check. Mann–Whitney *U* test was applied to non-parametric data. Statistical Package for the Social Sciences 22.0 package program was used for all analysis (IBM Corporation; Armonk, NY, USA). Values with $P < .05$ were considered statistically significant.

RESULTS

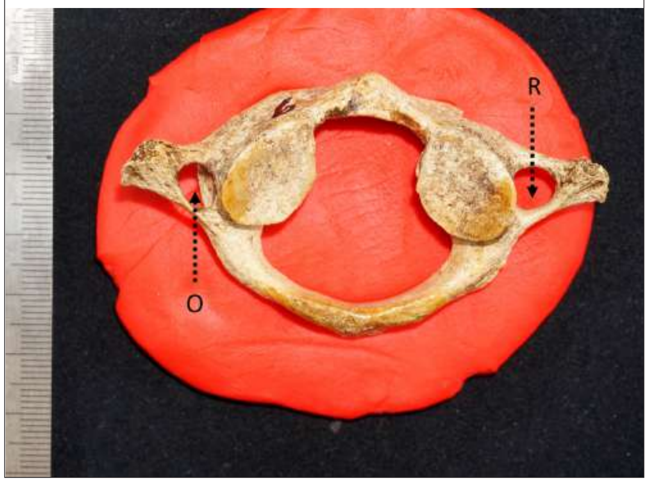
The values of 14 parameters that were examined on the atlas vertebrae are shown in Table 1. Nine of these parameters (P4, P5, P6, P7, P8, P11, P12, P13 and P14) were examined bilaterally, and no statistically significant difference was found between the sides ($P = .865$, $P = .962$, $P = .339$, $P = .394$, $P = .394$, $P = .091$, $P = .566$, $P = .976$, and $P = .838$, respectively). Also, no accessory foramen transversarium was found in these atlas vertebrae (P16). Of the 23 foramina transversaria that were prominent and not broken, 7 were found to be round-shaped (30.43%), and 16 were oval-shaped (69.57%) (Figure 2).

Table 1. Results of Measured Parameters in the Atlas Vertebrae

Parameters	N	Mean ± SD	Range
P1	17	44.10 ± 3.50	39.40–53.70
P2	12	76.32 ± 8.09	64.10–90.20
P3	17	11.60 ± 1.82	9.20–15.20
P4 (R)	16	17.58 ± 2.29	14.20–24.00
P4 (L)	16	17.59 ± 2.14	14.50–23.80
P5 (R)	17	22.71 ± 3.15	16.70–29.00
P5 (L)	17	22.10 ± 3.41	17.70–32.10
P6 (R)	17	8.52 ± 1.61	5.10–11.00
P6 (L)	17	9.15 ± 1.88	5.40–13.00
P7 (R)	17	18.25 ± 2.05	13.40–22.00
P7 (L)	17	17.60 ± 2.06	13.80–20.50
P8 (R)	17	13.29 ± 1.42	9.90–15.60
P8 (L)	17	12.82 ± 1.70	9.60–15.90
P9	17	29.61 ± 3.21	24.40–36.70
P10	17	31.27 ± 2.76	27.60–38.60
P11 (R)	12	5.90 ± 0.97	4.70–7.80
P11 (L)	11	6.48 ± 0.69	5.30–7.40
P12 (R)	12	7.56 ± 0.93	6.30–9.30
P12 (L)	11	7.29 ± 0.62	6.30–8.20
P13 (R)	12	37.43 ± 7.85	23.70–51.70
P13 (L)	11	37.31 ± 6.27	27.60–45.70
P14 (R)	16	24.47 ± 2.14	20.50–28.80
P14 (L)	16	24.29 ± 1.81	21.70–28.10

R, right; L, left.
The unit for all parameters is mm except P13, and the unit for P13 is mm^2.

Figure 2. Shape of the foramen transversarium. O, oval-shaped; R, round-shaped.



DISCUSSION

The bones that make up the CVJ are the occipital bone, atlas, and axis. This region is the most complex area of the spine.[3,9] The atlas vertebra supports the skull, providing a unique positioning of the atlantoaxial complex.[7] Miller et al[10] stated that many techniques could be used during the stabilization of cervical spine injuries such as anterior plating, posterior wirings or Harrington/Luque rods with wires, posterior lateral mass plating, and posterior pedicle screw fixation. On the other hand, new surgical techniques and instrumentation for the treatment of unstable cervical spine continue to evolve. Therefore, detailed knowledge of the anatomy of the bones in the CVJ and surrounding structures becomes even more important.[4,8]

In addition, the relationship between the vertebral artery and the groove for the vertebral artery of the atlas vertebrae has an essential role in the operative approaches to be applied to this region.[4] Screw fixation can be used in atlas instabilities.[4] Although pedicle screw fixation provides the strongest stability for cervical reconstruction, there is a risk of neurovascular injury during this procedure. Moreover, various complications such as the vertebral artery, nerve root, and spinal cord injuries and infections may also occur due to this procedure.[11,12] More dramatically, even very serious problems such as cerebral infarction or death can occur due to injury to the bilateral vertebral arteries.[13] When all these complications are considered, it is extremely important to know the morphology, morphometry, and variation of the all-anatomic structures on the atlas.

Sanchis-Gimeno et al[14] stated that the cervical variants should be known before any surgery is performed. In addition, anatomical

Table 2. Literature Comparison of Parameters Related to the Atlas Vertebrae

Study	P1	P2	P3	P4		P5		P6		P7		P8		P9	P10
				R	L	R	L	R	L	R	L	R	L		
Christensen et al[2]	45.67 ± 3.61	75.61 ± 5.94	6.02 ± 1.02												
Gosavi and Vatsalaswamy[7]		69.37 ± 6.47	10.33 ± 1.67			21.24 ± 2.39	21.02 ± 2.52	10.36 ± 1.72	10.47 ± 1.61	16.57 ± 1.91	16.50 ± 1.67	14.01 ± 1.93	14.42 ± 1.67	26.89 ± 1.93	25.66 ± 2.59
Jasveen et al[16]						21.52 ± 2.36	21.51 ± 2.07	11.21 ± 1.47	11.32 ± 1.53	17.54 ± 1.50	17.70 ± 1.60	14.99 ± 1.65	14.94 ± 1.51		
Naderi et al[1a]	43.22 ± 2.45	74.74 ± 5.81	6.66 ± 0.85	15.03 ± 1.22		19.94 ± 2.42									30.24 ± 2.30
Naderi et al[1b]	43.35 ± 2.37	74.97 ± 5.53	6.23 ± 1.06	14.61 ± 1.17		19.94 ± 2.00									30.68 ± 2.45
Rocha et al[19]	46.60 ± 3.20	78.90 ± 6.40		15.0 ± 1.6	14.8 ± 1.6	23.9 ± 2.5	23.6 ± 2.5			18.8 ± 1.7	18.7 ± 1.6	16.6 ± 2.0	16.4 ± 2.0		32.6 ± 1.8
Şengül and Kadıoğlu[4]	46.20 ± 6.00	74.60 ± 9.70		16.2 ± 2.5	15.8 ± 2.4	19.9 ± 3.4	18.6 ± 3.2	9.6 ± 1.9	9.8 ± 1.5	17.1 ± 2.6	17.5 ± 2.4	14.6 ± 2.5		28.7 ± 1.8	31.4 ± 3.5
Tun[22]			7.00 ± 1.20												
Present study	44.10 ± 3.50	76.32 ± 8.09	11.60 ± 1.82	17.58 ± 2.29	17.59 ± 2.14	22.71 ± 3.15	22.10 ± 3.41	8.52 ± 1.61	9.15 ± 1.88	18.25 ± 2.05	17.60 ± 2.06	13.29 ± 1.42	12.82 ± 1.70	29.61 ± 3.21	31.27 ± 2.76

[a]Direct morphometric measurement; [b]Computed tomography measurement.
The unit for all parameters is mm.
R, right; L, left.

Table 3. Literature Comparison of Parameters Related to the Foramen Transversarium of Atlas Vertebrae

Study	P11 (mm)		P12 (mm)		P13 (mm²)		P14 (mm)	
	R	L	R	L	R	L	R	L
Rocha et al[19]	6.6 ± 0.9	6.5 ± 0.9	7.3 ± 1.1	7.2 ± 1.1			24.1 ± 1.8	23.8 ± 1.8
Lalit et al[18]	5.17 ± 1.09	5.40 ± 1.11	6.72 ± 1.05	6.90 ± 0.99				
Taitz et al[21]	5.52 ± 0.93	5.76 ± 0.98	7.26 ± 0.87	7.23 ± 0.98				
Karau Bundi et al[17]			5.11	5.16	36.30	37.20		
Sethi et al[20]			5.3	5.1	30.46	30.82		
Present study	5.90 ± 0.97	6.48 ± 0.69	7.56 ± 0.93	7.29 ± 0.62	37.43 ± 7.85	37.31 ± 6.27	24.47 ± 2.14	34.29 ± 1.81

R, right; L, left.

variations of the atlas should be investigated further before the procedure in patients undergoing spine surgery.[14] On the other hand, Kaur et al[15] stated that since there are so many variations in this region, it is challenging to operate according to predetermined size standards. Moreover, it has been reported that this region's morphological and morphometric characteristics may also differ between different ethnic groups and races.[7] Therefore, the anatomy of the bony structures in the CVJ, such as the atlas vertebrae, should be well known in order to reduce complications and increase success during the procedures to be applied to this region.

Morphometry of the Atlas Vertebra

There are many studies in the literature examining the morphometry of the atlas vertebrae.[1,4,7,16-22] In this study, the parameters evaluated in previous studies were compiled and compared (Tables 2-3). Although most of these studies evaluated dry bone, both dry bone and computed tomography images were used in the study by Naderi.[1] It is known that the most critical disadvantage of dry bone studies is the lack of information about age, gender, and ethnicity.[23] Therefore, it is deducted that these studies on dry bones will help to have an idea about this region rather than determining standard reference values.

In atlantoaxial dislocation, spinal epidural abscess, and odontoid process fractures, the spine can be reached by a transoral approach.[24] During this procedure, the anterior arch of the atlas can be resected to reach the odontoid process. In this case, it is important to know the anteroposterior dimension of the anterior arch of the atlas vertebra (*P3*).[22] Distance between midline and groove for vertebral artery (P4) is vital for the close neighborhood of the vertebral artery and the area where the surgery will be performed. This distance should be known especially in order to perform laminectomy safely.[22] According to Steel's rule of thirds, the sagittal diameter of the vertebral foramen of the atlas (P10) is divided into 3 equal parts: one-third cord, one-third odontoid, and one-third space (safe zone).[25] For this reason, knowing the sagittal diameter of the vertebral foramen of the atlas (P10) can give an idea about the safe zone in surgical procedures. The number, size, and shape of the foramen transversarium may affect the morphology of the vertebral artery, causing vertebrobasilar insufficiency. Depending on the morphology and morphometry of the foramen transversarium, vertebral artery compression may occur. This situation may cause clinical symptoms such as chronic headaches, migraines, and fainting attacks.[6] Moreover, Taitz et al[21] stated that foramen transversarium and vertebral vessels are interrelated, and it can be assumed that variations of the vertebral vessels may manifest as variations of the foramen transversarium. Therefore, it is essential to know the transverse (P11) and anteroposterior (P12) diameters, area (P13), and shape (P15) of the foramen transversarium.

Limitations

The most important limitation of this study is that information about bones such as age, gender, and ethnic origin is not known.

CONCLUSION

It is deducted that the results obtained in this study will help to have information about the morphometry and morphology of atlas vertebrae. Although information such as age, gender, and ethnic origin is not known about the bones evaluated, it is the advantage of this study that a large number of parameters are evaluated and compared with previous publications. Nevertheless, it seems that there is a need for studies in which much more cases are assessed, and information such as age, gender, and ethnic origin is known.

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REFERENCES

1. Naderi S, Cakmakçi H, Acar F, Arman C, Mertol T, Arda MN. Anatomical and computed tomographic analysis of C1 vertebra. *Clin Neurol Neurosurg*. 2003;105(4):245-248. [CrossRef]
2. Chen YF, Liu HM. Imaging of craniovertebral junction. *Neuroimaging Clin N Am*. 2009;19(3):483-510. [CrossRef]
3. Tanrisever S, Orhan M, Bahşi İ, Yalçin ED. Anatomical evaluation of the craniovertebral junction on cone-beam computed tomography images. *Surg Radiol Anat*. 2020;42(7):797-815. [CrossRef]
4. Şengül G, Kadıoğlu HH. Morphometric anatomy of the atlas and axis vertebrae. *Turk Neurosurg*. 2006;16(2):69-76.
5. Cacciola F, Phalke U, Goel A. Vertebral artery in relationship to C1-C2 vertebrae: an anatomical study. *Neurol India*. 2004;52(2):178-184.
6. Akhtar M, Madhukar P, Rahman S, Kashyap N. A morphometric study of foramen transversarium of dried cervical vertebrae. *Int J Res Med Sci*. 2015;3(4):912-916. [CrossRef]
7. Gosavi SN, Vatsalaswamy P. Morphometric study of the atlas vertebra using manual method. *Malays Orthop J*. 2012;6(3):18-20. [CrossRef]
8. Doherty BJ, Heggeness MH. Quantitative anatomy of the second cervical vertebra. *Spine (Phila Pa 1976)*. 1995;20(5):513-517. [CrossRef]
9. Koller H, Robinson Y. *Cervical Spine Surgery: Standard and Advanced Techniques*. Berlin: Springer; 2019.
10. Miller RM, Ebraheim NA, Xu R, Yeasting RA. Anatomic consideration of transpedicular screw placement in the cervical spine. An analysis of two approaches. *Spine (Phila Pa 1976)*. 1996;21(20):2317-2322. [CrossRef]
11. Yukawa Y. Pedicle screw fixation in cervical spine. In: Koller H, Robinson Y, eds. *Cervical Spine Surgery: Standard and Advanced Techniques*. Cham: Springer International Publishing; 2019:449-454.
12. Panjabi MM, Shin EK, Chen NC, Wang JL. Internal morphology of human cervical pedicles. *Spine (Phila Pa 1976)*. 2000;25(10):1197-1205. [CrossRef]
13. Yukawa Y, Kato F, Ito K, et al. Placement and complications of cervical pedicle screws in 144 cervical trauma patients using pedicle axis view techniques by fluoroscope. *Eur Spine J*. 2009;18(9):1293-1299. [CrossRef]

14. Sanchis-Gimeno JA, Llido S, Perez-Bermejo M, Nalla S. Prevalence of anatomic variations of the atlas vertebra. *Spine J*. 2018;18(11):2102-2111. [CrossRef]
15. Kaur J, Kaur K, Singh P, Kumar A. Morphometric study of axis vertebra in subjects of Indian origin. *IJMDS*. 2018;7(1):1615-1620. [CrossRef]
16. Jasveen K, Harsimran G, Poonam S, Ajay K. Morphometric study of the articular facets of atlas and axis vertebrae. *UJMDS*. 2014;2(02): 83-89.
17. Karau Bundi P, Ogeng´o JA, Hassanali J, Odula PO. Morphometry and variations of bony ponticles of the atlas vertebrae (C1) in Kenyans. *Int J Morphol*. 2010;28(4):1019-1024. [CrossRef]
18. Lalit M, Kullar JS, Piplani S, Kullar G, Sharma T. Anatomical observations including morphometric pattern of foramina Transversaria of atlas vertebrae in North Indians. *Eur J Anat*. 2015;19(3):249-255.
19. Rocha R, Safavi-Abbasi S, Reis C, et al. Working area, safety zones, and angles of approach for posterior C-1 lateral mass screw placement: a quantitative anatomical and morphometric evaluation. *J Neurosurg Spine*. 2007;6(3):247-254. [CrossRef]
20. Sethi M, Vasudeva N, Mishra S. Study of foramen transversaria of first cervical vertebrae and its variations. *OA Anat*. 2014;2(3):25.
21. Taitz C, Nathan H, Arensburg B. Anatomical observations of the foramina Transversaria. *J Neurol Neurosurg Psychiatry*. 1978;41(2):170-176. [CrossRef]
22. Tun MK. *Transoral Yaklaşımda Dens Axis ile Arteria Vertebralis İlişkisi ve Atlas'ın Anatomik Önemi*; Doktora tezi, Ankara Üniversitesi, 2007.
23. Bahsi I. An anatomic study of the supratrochlear foramen of the humerus and review of the literature. *Eur J Ther*. 2019;25(4):295-303. [CrossRef]
24. Wang Y, Yang M, Zhang H, Zheng Y, Tian Y, Li Y. Exploring the safety range via the transoral approach to the craniovertebral junction. *J Craniofac Surg*. 2014;25(4):1473-1475. [CrossRef]
25. Steel H. Anatomical and mechanical considerations of the atlanto-axial articulations. *J Bone Joint Surg [Am]*. 1968;50:1481-1482.