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Surgical anatomy of the subaxial cervical spine pedicles: a cadaver study

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Abstract

Purpose

Subaxial cervical pedicle screws provide superior mechanical strength compared to lateral mass screws, but their insertion is technically challenging due to narrow pedicles and the proximity of the vertebral artery. Since many spine surgeons still use freehand technique due to limited availability of navigation, knowledge of local bony landmarks is essential. This cadaveric study aimed to determine the surgically relevant morphometric data of subaxial cervical pedicles and to define the relationship between an ideally placed pedicle screw and various posterior bony landmarks.

Methods

A total of 70 subaxial vertebrae (C3–C7) from 14 cadaveric spines were measured using a digital caliper and an inclinometer. Pedicle sizes, screw insertion points, and angles were determined in relation to the bony structures exposed during posterior cervical surgery.

Results

A generalized entry site for a subaxial pedicle screw was defined as an ellipsoid located at 2 mm below the horizontal line, 5 mm medial to the vertical line, and 20 mm lateral to the midline. The mean medial angulation was 32 degrees and the sagittal angle was 79 degrees. The width of 9.3% of pedicles was less than 4 mm. The total screw length ranged from 22.4 to 37.3 mm.

Conclusion

Although most morphometric parameters were similar on both sides, the left-sided pedicle screw lengths were approximately 2 mm greater at all levels. The posterior face of the facet was a more reliable landmark for the sagittal screw angle than the spinous process. These findings emphasize the importance of individual preoperative planning in subaxial cervical pedicle screwing.

Introduction

Structural and functional integrity of the cervical spine may be compromised by degenerative, neoplastic, infectious diseases, trauma or decompression surgery.[2–3, 7–8] When cervical instability occurs, posterior cervical instrumentation is frequently indicated. In the subaxial region (C3-C7), the traditional anchor point for screw fixation is the lateral mass, except C7 level. Lateral mass offers acceptable holding power with minimum surgical risk. Recently, pedicle screw fixation in the subaxial vertebrae has been rising in popularity due to its superior mechanical strength.

However, fine structure of the pedicle and its proximity to the vertebral artery as well as the neural structures make the use of pedicle screws in the cervical region difficult. Use of intraoperative navigation may decrease surgical risks considerably. However, because that technology is not ubiquitously available, many spine surgeons still use freehand screw insertion technique, similar to that of thoracic and lumbar regions. For an uncomplicated application of freehand cervical pedicle screws, excellent knowledge of the regional anatomy and the appropriate selection of the entry point, angle and depth of the screw is essential.[9, 14]

Previously, feasibility of pedicle screw fixation in the subaxial cervical spine has been investigated in some studies. In this cadaver study, we aimed to provide a complete map of posterior subaxial anatomy to determine the optimal entry point, angle and depth of pedicle screw insertion. In order to provide useful, practical values, we focused on the relationship between an ideally placed pedicle screw and various posterior bony structures such as the lateral masses, laminae, and spinous processes which are bony structures exposed during posterior surgery.

Methods

In this study, we used the cervical vertebrae of 14 cadavers, including 13 male and one female, which were used in the education of students and kept in formaldehyde pool in Trakya University School of Medicine, Department of Anatomy. Approval was received from our institutional ethics board for this study (TÜTFEK2006017). In the first stage, the vertebrae of cadavers were divided into the blocks and numbered. At the second stage, the vertebrae were divided individually, and the soft tissues were removed with sharp dissection. By keeping in a mixture of water (1:1) and hypochlorite bleach (5.25%), the remaining tissues were removed. The vertebra was then kept in 70% ethanol bath for 1 hour and dried (2). Each of the cadaver spines was numbered.

A digital calliper conducted the distance measurements with a sensitivity of 0.01 mm, and angle measurements were conducted by an inclinometer (magnetic angle gauge) with a sensitivity of 1 degree.

The measurement criteria of the study were as follows:

1-) **The craniocaudal height of the pedicle (CCPH)** shows the pedicle height (Fig. 1)

(Fig. 1)

2-) **The mediolateral width of the pedicle (MLPW)** shows the pedicle width (Fig. 2)

(Fig. 2)

3-) **The length of facet (FL)** shows the facet length (a) (Fig. 3)

4-) **The length of the pedicle (PL)** shows the pedicle length (b) (Fig. 3)

5-) **The depth of the corpus in the midline (MLCD)** shows the length of the corpus in the direction that pedicle screw pass through (c) (Fig. 3)

6-) **The total length of the pedicle screw (TLPS)** shows the distance traveled by an imaginary pedicle screw which is extending from the facet to the anterior cortex of the vertebral corpus (d) (Fig. 3)

(Fig. 3)

7-) **Sagittal pedicle angle (SPA)** shows the surgical angle between the lateral mass and pedicle screw (Fig. 4)

(Fig. 4)

8-) **Spinous process pedicle angle (SPPA)** shows the angle between the pedicle screw and spinous process (Fig. 5)

(Fig. 5)

9-) **Transverse pedicle angle (TPA)** (medial angulation of the screw) shows the angle between the pedicle screw and the line dividing the spine from front to back centrally (Fig. 6)

(Fig. 6)

10-) **Height of the lateral mass (LMH)** shows the vertical length of the lateral mass (Fig. 7)

(Fig. 7)

11-) **The width of the lateral mass (LMW)** shows the lateral width of the mass from the posterior aspect (Fig. 8)

(Fig. 8)

12-) **The height of the lamina (LH)** shows the vertical size of the lamina (Fig. 9)

(Fig. 9)

13-) **The width of the lamina (LW)** shows the size of the lamina between lateral mass and spinal process (Fig. 10)

(Fig. 10)

14-) **The distance between the pedicles (PD)** shows the distance between the midpoints of the pedicles (Fig. 11)

(Fig. 11)

15-) **The horizontal line (HL)** shows the distance from the entry site of the pedicle screw to the horizontal line connecting the lower edges of the both upper facets (Fig. 12)

(Fig. 12)

16-) **Vertical line (VL)** shows the distance from the entry site of the pedicle screw to the end of the lateral mass (Fig. 13)

(Fig. 13)

17-) **The distance from the midline (MDL)** shows the distance from the entry site of the pedicle screw to the midline of the vertebra (Fig. 14)

(Fig. 14)

A digital calliper conducted the distance measurements with a sensitivity of 0.01 mm, and angle measurements were conducted by an 'inclinometer' (magnetic angle gauge) with a sensitivity of 1 degree.

Statistical Methods: Minitab software version 13.1 was used for statistical analysis (serial no: WCP 1331.00197). A t-test was performed for evaluating the difference between right and left sides. A p-value of < 0.05 was considered to be statistically significant.

Results

The mean distance from the horizontal line (a in Fig. 15) was 1.8 mm, 1.4 mm, 1.9 mm, 2.3 mm, and 3 mm C3, C4, C5, C6 and C7 respectively. The mean distance from the vertical line (b in Fig. 15) was 3.6 mm, 3.7 mm, 4.7 mm, 5.4 mm, and 5.8 mm; the mean distance from the midline (c in Fig. 15) was 19.8 mm, 19.9 mm, 20.1 mm, 19.9 mm, and 19.5 mm at C3, C4, C5, C6 and C7 respectively. Average craniocaudal height of the pedicles was 7,2 mm, and mediolateral width was 5,6 mm.

A generalized entry site for a subaxial pedicle screw should be an ellipsoid located at 2 mm below the horizontal line (a), 5 mm medial to the vertical line (b) and 20 mm lateral to the midline (c); with a height of 7 mm and width of 5 mm.

The amount of medial angulation of the screw (transverse pedicle angle) was found 33.4 degrees, 33.3 degrees, 33.1 degrees, 31.3 degrees, and 29.6 degrees C3, C4, C5, C6 and C7 respectively. The average medialisation angle was 32 degrees, and the sagittal angle between the pedicle axis and the posterior wall of the lateral mass was 79 degrees. A subaxial cervical pedicle screw should incline on average 32 degrees medial and 79 degrees caudal.

The width of 13 of the total 140 pedicles (9,3%) was noticed to be less than 4 mm. When a pedicle screw was put on in a fashion that it reached to the anterior wall of the corpus; its 9 to 10 mm part was in lateral mass, 5 to 6 mm was in the pedicle, and 15 to 17 mm was in the corpus. However, it was found that this length can be as short as 22,4 mm, and as long as 37,3 mm.

The average height of the lateral mass was 12.9 mm, the width of the lateral mass was 11.2 mm, the height of the lamina was 12.7 mm, the width of the laminae was 16 mm, and the distance between the pedicles was 27.8 mm.

The calculated values for all parameters are summarised in Table 1 separately. While the measurements of the right and left side generally gave similar results, there were significant differences in some parameters ($p < 0.05$). At all levels (C3-C7), the depth of the corpus in the midline and the length of pedicle screws was significantly greater in the left side than the right side. Also, the total length of the pedicle screws at all levels was found to be significantly greater in the left side than the right side. In the measurements of the craniocaudal height of pedicles, a significant difference was found between right and left sides. Although the mediolateral pedicle width of the right side was greater than that of the left side at all levels, the difference was significant only at the level of C4 ($p = 0.01$).

Table 1
The measurements of the right and left cervical pedicles and analysis of the difference between them

Parameter		C3			C4			C5			C6			C7		
	Side	Avg	SD	p*	Avg	SD	p	Avg	SD	p	Avg	SD	p	Avg	SD	p
CCPH	Right	7.60	1.00	0.09	7.60	0.90	0.36	7.10	1.00	0.53	6.70	0.90	0.22	7.50	0.80	0.42
	Left	7.30	0.80		7.80	1.10		7.00	1.10		6.50	1.30		7.30	1.40	
MLPW	Right	5.10	0.90	0.37	5.50	0.90	**0.01**	5.50	0.80	0.59	5.90	1.00	0.17	6.80	1.00	0.08
	Left	4.90	1.20		5.00	0.80		5.40	1.00		5.50	1.00		6.40	1.20	
FL	Right	10.00	1.90	0.34	10.00	2.00	0.24	9.40	2.00	0.45	8.20	1.60	0.44	7.30	0.90	0.53
	Left	10.70	2.50		10.50	2.20		9.70	2.90		8.50	1.90		7.70	1.50	
PL	Right	5.90	1.40	0.29	5.40	1.00	**0.05**	5.00	1.30	0.59	5.60	1.30	0.52	6.20	0.80	0.77
	Left	5.60	1.30		4.90	1.10		5.10	1.00		5.80	1.40		6.30	0.80	
MLCD	Right	14.50	2.10	**0.01**	15.90	2.20	**0.02**	16.40	1.60	**0.05**	17.10	2.50	**0.05**	17.20	2.10	**0.03**
	Left	15.70	2.10		16.70	2.20		17.10	1.50		18.10	2.10		18.10	2.30	
TLPS	Right	27.40	3.20	**0.00**	27.20	2.30	**0.00**	28.00	2.90	**0.00**	28.30	3.30	**0.00**	28.30	2.20	**0.01**
	Left	29.40	3.10		29.40	2.20		30.00	3.00		30.30	2.70		29.70	2.70	
SPA	Right	82.80	6.90	0.33	85.20	4.10	0.30	75.10	8.60	0.11	75.00	7.90	0.36	75.30	8.40	0.85
	Left	83.60	8.30		84.00	5.10		78.50	9.50		76.50	10.20		75.50	8.90	
SPPA	Right	37.90	10.60	0.84	39.20	6.90	**0.01**	38.10	11.80	0.68	28.60	7.00	**0.02**	26.40	6.10	0.38
	Left	38.20	9.30		41.50	6.80		38.70	9.60		31.20	8.40		26.80	6.60	
TPA	Right	32.80	6.10	0.44	31.60	3.20	**0.02**	33.20	4.90	0.82	30.30	3.80	0.14	28.60	4.80	0.11
	Left	34.10	4.50		34.90	3.90		32.90	5.60		32.30	4.30		30.60	6.00	
LMH	Right	12.90	1.60	0.77	12.50	1.90	0.07	11.40	1.80	**0.03**	13.10	1.60	0.31	15.70	2.20	0.56
	Left	12.80	2.30		11.30	1.90		12.20	1.90		12.40	2.30		15.20	2.30	
LMW	Right	9.90	2.00	0.88	10.70	2.10	0.55	11.70	1.50	0.81	12.00	1.70	0.17	11.80	1.50	0.72
	Left	10.00	2.10		11.30	4.30		11.60	2.50		11.50	1.40		11.70	1.50	
LH	Right	11.50	1.40	**0.03**	11.10	1.60	0.19	11.50	1.30	0.22	13.30	1.40	0.79	16.10	2.20	0.18
	Left	11.00	1.50		11.50	1.70		11.90	0.90		13.20	1.40		16.40	2.30	
LW	Right	16.20	1.90	0.06	15.90	1.20	0.15	15.90	1.00	0.63	16.50	1.80	0.52	16.90	1.80	0.07
	Left	15.50	2.30		15.20	2.00		15.80	1.40		16.20	1.80		15.80	2.50	
HL	Right	1.70	0.80	0.27	1.60	1.00	0.14	1.80	1.20	0.24	2.40	1.00	0.35	3.30	1.90	0.31
	Left	1.90	0.90		1.20	0.50		2.10	1.20		2.20	0.90		2.80	1.30	
VL	Right	3.80	1.00	0.09	4.00	0.90	0.18	4.80	1.20	0.67	5.70	1.50	0.24	5.80	1.40	0.78
	Left	3.40	0.60		3.40	1.10		4.70	1.40		5.10	1.60		5.90	1.20	
DML	Right	19.80	1.40	0.98	19.40	1.60	**0.02**	19.70	1.80	0.08	19.50	1.70	**0.05**	19.10	2.00	0.11
	Left	19.80	1.20		20.50	1.60		20.40	2.10		20.20	2.10		19.80	2.00	

CCPH: Craniocaudal pedicle height; MLPW: Mediolateral pedicle width; FL: Facet length; PL: Pedicle length; MLCD: Midline corpus depth; TLPS: Total length of the pedicle screw; SPA: Sagittal pedicle angle; SPPA: Spinous process pedicle angle; TPA: Transverse pedicle angle; LMH: Lateral mass height; LMW: Lateral mass width; LH: Lamina height; LW: Lamina width; HL: Horizontal line; VL: Vertical line; DML: The distance from the midline; Avg: Average; SD: Standard deviation. * T-test

The length of the pedicle on the right side was found to be greater than that of the left side only at the level of C4 ($p = 0.05$). The pedicle angle of the spinous process was greater in the left side at all levels, although the difference was significant only at the levels of C4 and C6 ($p = 0.01$ and $p = 0.02$ respectively). Transverse pedicle angle was significantly greater in the left side only at the level of C4 ($p = 0.02$). The height of the lateral mass of the left side was significantly greater only at the level of C5 ($p = 0.03$).

Height of the laminae on the right side was found to be significantly greater than that of the left side only at the level of C3 ($p = 0.03$). The distance from the midline was significantly greater in the left side than right side at the levels of C4 and C6 ($p = 0.02$ and $p = 0.05$ respectively.

Discussion

By obtaining direct morphometric data of three-dimensional local bony anatomy, cadaver studies have a significant role in determining the safest freehand insertion technique of pedicle screws. In our study, measurements of the cervical pedicles were performed bilaterally, and the results were reported separately. In most studies, no difference was found between the sides. However, Shin et al. reported that there may be a difference between the diameters of the pedicle of right and left sides and that cervical pedicles showed individual differences [12]. In our study, the parameters of the right and left sides were generally comparable, but no difference was found in the total length of the pedicle screw.

At all levels, the pedicle screw lengths of the left side were found to be 2 mm greater. This difference is mainly due to the part of the screw moving in the corpus. We do not have a definite opinion on the leading cause of this difference. However, age-induced degeneration can be considered to affect the osteophytes tendencies in facet and corpus areas and the process of bone remodelling on the right and left sides differently. This difference may be caused by the use of right and left sides at different rates because of the hemisphere dominance and the usual position of the head. We think that this 2-mm difference could be substantial and that it should be considered during the screw selection.

Batir et al. [16] recently analyzed subaxial cervical pedicle morphometry in 60 Turkish adults using computed tomography and reported that pedicle widths that did not accommodate a standard 3.5-mm screw were present in both males and females. Their mean bilateral pedicle width in males was greater than in females, consistent with previous literature. Although their study used a different methodology (CT imaging vs. direct cadaveric measurement), the overall trends are comparable with our findings, reinforcing the validity of both approaches in the Turkish population.

Several population-based studies have shown significant ethnic variability in cervical pedicle dimensions. For example, Kumar et al. [21] analyzed CT scans of 2400 pedicles in the Indian population and found the smallest mean pedicle width at C3 (4.85 mm in males, 4.31 mm in females), with 7.08% of all pedicles having a width less than 4 mm. Similarly, Farooque et al. [17] reported mean pedicle widths ranging from 4.3 mm at C3 to 5.7 mm at C7 in another Indian cohort. Also, Herrero et al. [18] conducted a CT-based study of a Brazilian population and found that pedicle width was less than 4 mm in 7.5% of men and 25% of women at C3 level. In addition, Jonathan et al. [19] reported remarkably smaller pedicle dimensions in a Ugandan population, with a mean width of only 1.65 mm at C3, which is dramatically lower than the values reported in Western, Asian, or our Turkish population. In our study, the mean pedicle width ranged from 5.0 mm at C3 to 6.6 mm at C7, and 9.3% of all pedicles had a width less than 4 mm — a proportion comparable to the Indian data but lower than the Brazilian female data. These cross-population comparisons show the importance of population-specific morphometric data for preoperative planning and screw size selection.

It is a critical point that the diameter of the screw must be appropriate to the pedicles. If the screw has a larger diameter, loosening of the implant or injury to adjacent visceral structures may develop as a result of pedicle fracture. Karaikovic et al. have measured the width and height of 636 pedicles by using computed tomography and found that pedicle height was larger than the width in 88.1% of cases, was equal to the width in 9.6% of cases and was smaller than the width in 2.4% of cases [6]. Moreover, Ebraheim et al. have stated that the width of the pedicle was the most critical factor in safe screw placement as the height of the pedicle is always greater than the width of the pedicle [4]. Our measurements also showed that the height of pedicle is larger than the width of the pedicle.

In the literature, pedicle width and height values show some differences. Anderson suggested that the width of the cervical pedicle is very narrow and usually a screw smaller than 4.5 mm in diameter is needed [1]. Ebraheim et al. have found pedicle width as 5.7 to 6.3 mm between C3 and C6 vertebrae [4]. We calculated the mean width of the pedicle as 5 mm at C3, 5.2 mm at C4, 5.4 mm at C5, 5.7 mm at C6, and 6.6 mm at C7.

Ebraheim et al. have found the mean height of the pedicles as 6.7 to 7.6 mm between C3 and C6 vertebrae [4]. Researchers have found the mean height of the smallest pedicle as 4.7 mm at C3 and 6.4 mm at C6. We have found the mean height of pedicle as 7.4 mm at C3, 7.7 mm at C4, 7.1 mm at C5, 6.6 mm at C6, and 7.4 mm at C7. In our study, the mean height of the smallest pedicle was found 6.6 mm at the level of C6.

It is possible to encounter extremely thin or thick pedicles outside of the normal distribution. Ebraheim et al. [4] have measured the thinnest pedicle width as 3 mm at the level of C3 in females and as 3.1 mm at the level of C4 in males. Our measurements have shown the smallest pedicle width of 2.6 mm and 3.1 mm. In conclusion, the screws of 3.5 mm in diameter can be appropriate for the pedicles of the subaxial cervical spine. Nevertheless, one should consider that pedicles having a smaller width can be encountered occasionally.

In our study, how much distance an imaginary screw travels through three segments (through the lateral mass, the pedicle and the vertebral corpus) are measured both separately and totally. The total length of the screw was between 28 to 29 mm. However, the total length of the pedicle screw could be as short as 22.4 mm or as long as 37.3 mm. These findings are showing the importance of pre-operative planning.

The most crucial point in the application of a pedicle screw is the selection of the entry point and the orientation angle. The entry point should be on the line passing through the axis of the pedicle and adjusted according to the angle of the screw placement on lateral mass. The angle should be directed medially in the axial plane and mildly cranially in the sagittal plane.

Jeanneret et al. have conducted an anatomical study on articular mass fracture and transpedicular screw fixation in dislocations in cervical vertebrae, and have placed transpedicular screw at the middle of the lateral mass and 3 mm under the upper facet. The medial angle has been defined as 45 degrees at the transverse plane [5]. Anderson suggested that the least medial angulation is at C2 and C7 and the largest medial angulation is at C5 [1]. In our measurements, the least medial angulation was found at C7.

We have also evaluated the angle between the spinous process and the axis of the pedicle, which was another criterion not mentioned in previous studies. With this measure, we aimed to investigate whether we could properly orient the pedicle screw by considering the angle of the spinous process. When compared to the axis of the spinous process, an angle with a mean caudal rotation of 34 degrees was found suitable. However, the standard deviation is 10 degrees and this angle can vary between 12 and 61 degrees. Therefore, a sagittal angle that will be ascertained by considering the posterior face of the facet (for all levels, a mean of 79 ± 8.7 degrees), is seen to be more appropriate when compared to the angle of the spinous process.

Our generalized entry point which is an ellipsoid located at 2 mm below the horizontal line, 5 mm medial to the vertical line, and 20 mm lateral to the midline, provides a practical landmark for freehand insertion. Sandeep et al. [23] recently evaluated a freehand technique using the lateral vertebral notch as a reference point in 22 patients and reported an overall accuracy rate of 86.25%, with a complication rate of only 1.25%. Their mean screw angle of 23.43° ± 9.28° was notably lower than the mean medial angulation of 32° found in our study. This difference is likely due to the different reference points used and shows that entry point selection directly influences the trajectory angle. The entry site and angular data from our cadaveric study can serve as an additional reference for surgeons performing freehand screw insertion.

The importance of accurate morphometric data can be better understood when considering the outcomes of different screw placement techniques. In a systematic review and meta-analysis, Tarawneh et al. [24] analyzed 4278 cervical pedicle screws from 17 studies and found that navigation-assisted techniques had a significantly lower misplacement rate (12.5%) compared to fluoroscopy-guided techniques (18.8%, $p < 0.0001$). Furthermore, fluoroscopy-guided insertion was associated with a significantly higher incidence of neurovascular complications (1.9% vs 0.3%, $p = 0.038$). Ono et al. [22] similarly demonstrated that the use of a navigation-linked high-speed drill significantly reduced lateral deviations, which are the primary cause of vertebral artery injury.

Despite these benefits, Jung et al. [20] pointed out in their review that navigation technology is not available everywhere, has significant costs, and requires about 30 cases to overcome the learning curve. They noted that the freehand technique using a curved pedicle probe is still a valid option, especially in emergency situations. When navigation is not available, a good knowledge of local anatomy and posterior bony landmarks — as described in our study — is essential for safe screw placement. Our data on the relationship between the pedicle screw trajectory and posterior bony structures like lateral masses, laminae, and spinous processes are aimed to support the freehand approach.

During pedicle screw insertion, a good knowledge on these anatomical structures would provide a safer application.

Limitations

This study has several limitations. First, the sample size of 14 cadaver spines (70 subaxial vertebrae, 140 pedicles) is relatively small. Although this is comparable to other cadaveric studies, it limits the statistical power and generalizability of our findings. Second, 13 of the 14 cadavers were male, which prevented a meaningful analysis of sex-related differences — a factor shown to be significant in CT-based studies [21, 18]. Third, the cadavers were preserved in formaldehyde, which may cause some tissue shrinkage; however, direct measurements of bony dimensions with a digital caliper are considered reliable even in fixed specimens. Fourth, without CT correlation, the internal pedicle cortex thickness could not be assessed. Fifth, our sample was from a single center in Turkey and may not represent other populations, given the ethnic variability shown in the recent literature [17–19, 21]. Future studies with larger, sex-balanced cohorts and combined cadaveric-CT methodology would help validate these findings further.

Conclusions

Although most morphometric parameters of the subaxial cervical spine pedicles on both sides are usually similar, there are exceptions such as the depth of the corpus in the midline and the total length of the pedicle screw. At all levels, the left-sided pedicle screw lengths were found to be approximately 2 mm greater than the right side, which may have practical consequences during screw selection. The width of 9.3% of pedicles was less than 4 mm, confirming that not all subaxial cervical pedicles can safely accept a standard 3.5-mm screw.

Our data also showed that the posterior face of the facet is a more reliable reference for determining the sagittal screw angle than the spinous process. These findings, together with the entry point coordinates and angular data provided in this study, can help spine surgeons with freehand pedicle screw insertion when navigation is not available. We believe that individual preoperative planning remains essential for safe subaxial cervical pedicle screwing.

Declarations

Competing interests

The authors declare no competing interests.

Conflict of interest

The authors declare that they have no financial or non-financial interests that are directly or indirectly related to the work submitted for publication.

Ethics approval

All procedures performed in this study were in accordance with the 1964 Declaration of Helsinki, and an approval was received from the institutional ethics board of Trakya University for this study (TÜTFEK2006017).

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Author Contribution

All authors contributed to the study conception and design. A.T.A. designed the study, analyzed the data, and wrote the manuscript. B.B. performed measurements, assisted in study design and contributed to manuscript editing. M.E.A. contributed to data analysis and manuscript editing. C.K. supervised the study and critically reviewed the manuscript. All authors read and approved the final manuscript.

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Data Availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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Figures

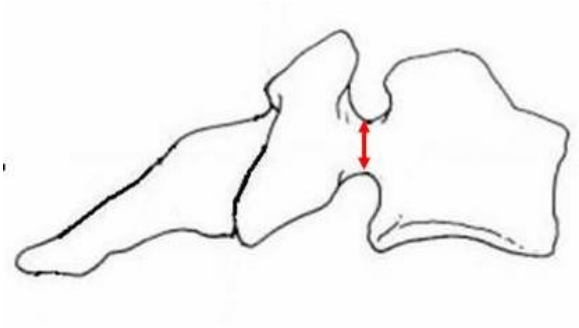


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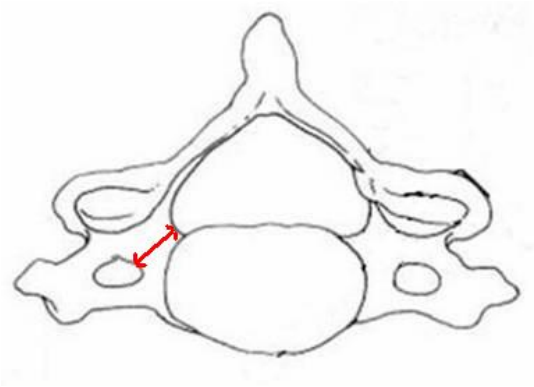


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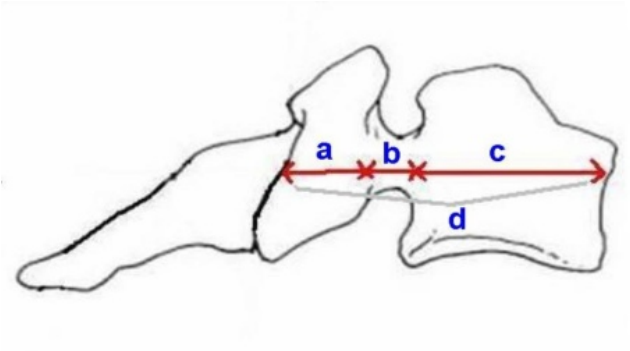


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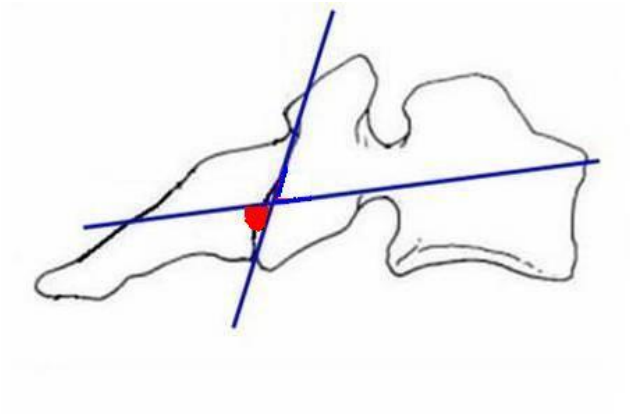


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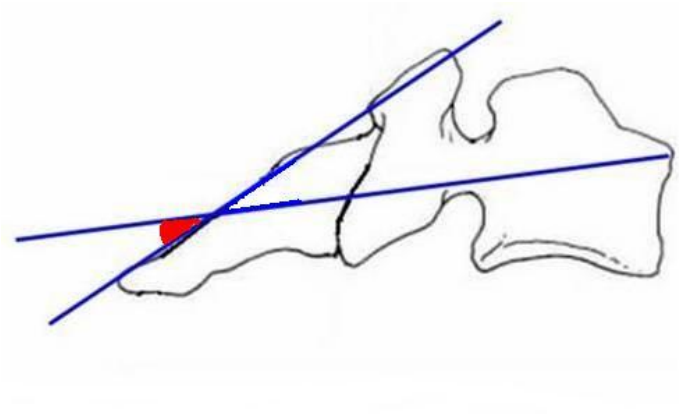


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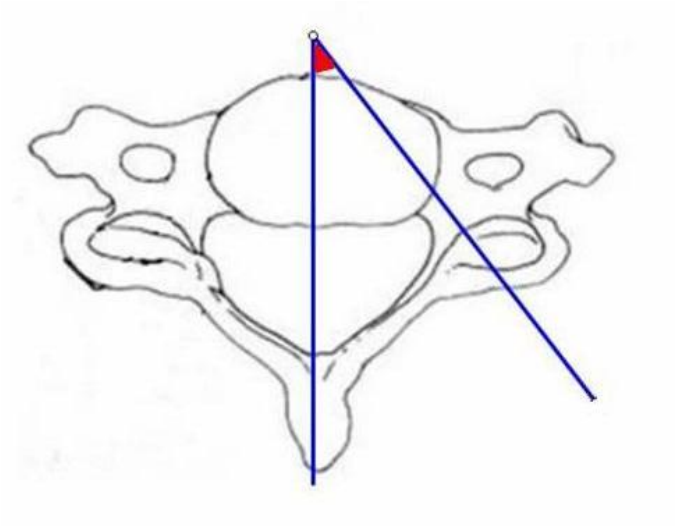


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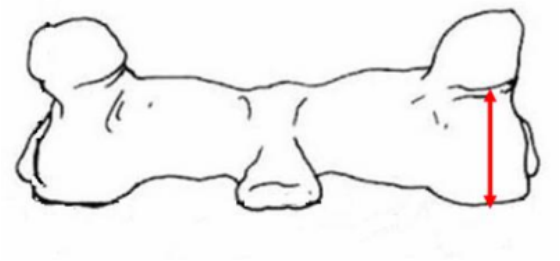


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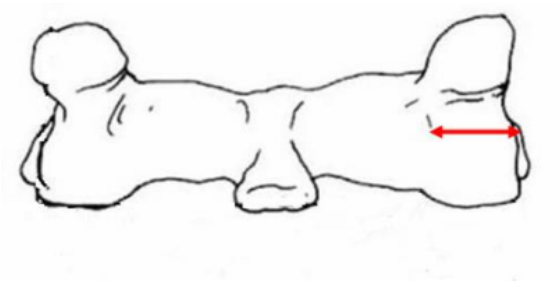


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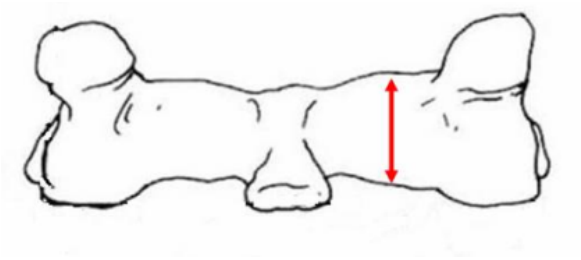


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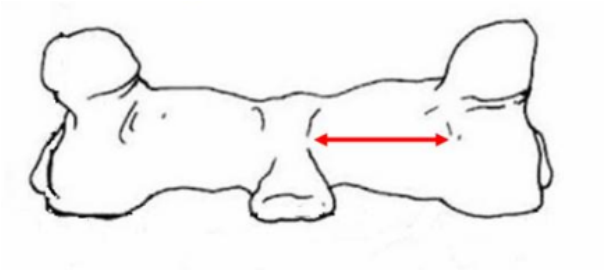


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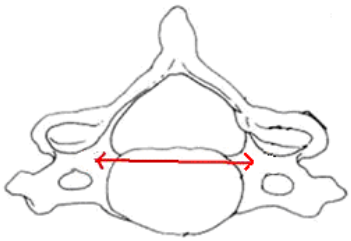


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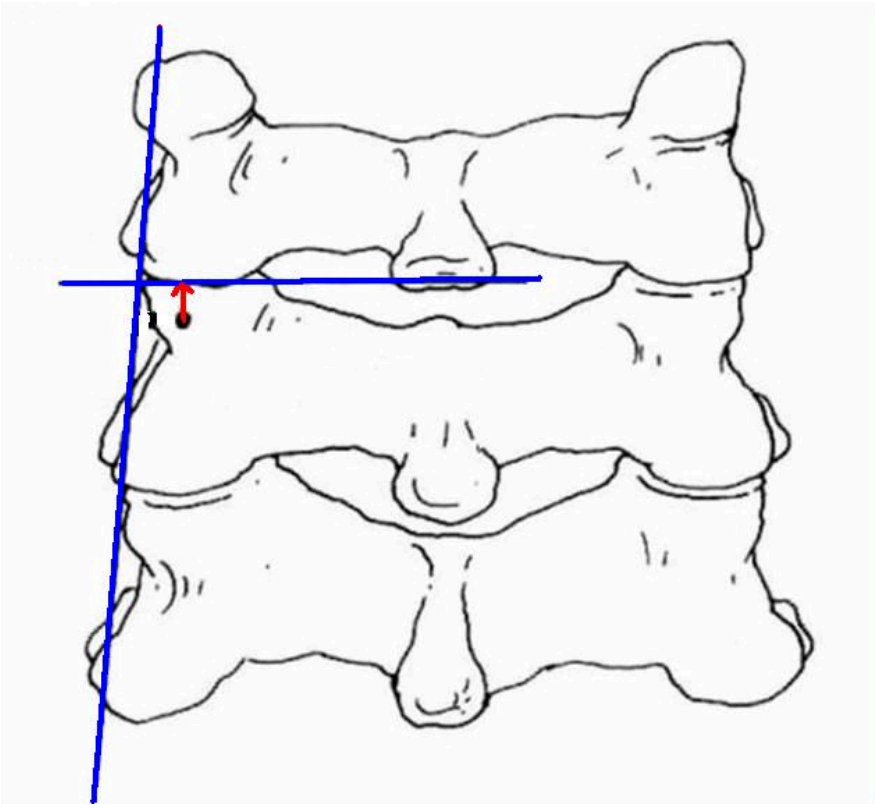


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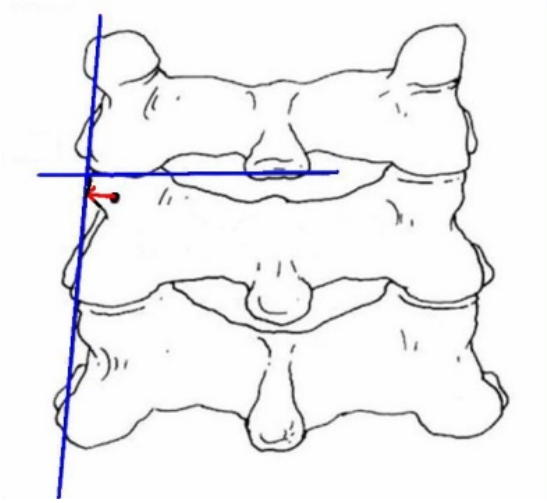


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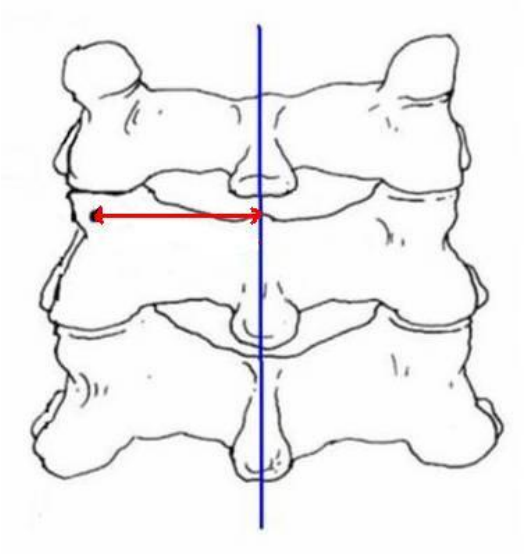


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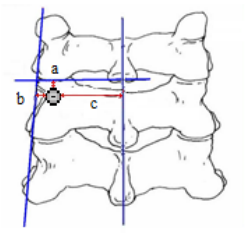


Figure 15

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