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Cervical vertebrae of South Indian population: A morphometric study with its implications on spine surgeries

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***Abstract*---**Introduction: Cervical vertebrae owing to their small size and complex anatomy pose a serious challenge for instrumentation during surgery and increase the risk of injury to the adjacent neurovascular structures. The aim of the study is to evaluate the linear measurements of the body, pedicle and foramen transversarium of C1 to C7 vertebrae and to correlate the data clinically. Methods:

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138 vertebrae of unknown sex and age were classified into individual cervical vertebrae and the linear dimensions of vertebral body, pedicle and foramen transversarium were measured using digital vernier caliper. Shape of foramen transversarium and presence of accessory foramen were noted. Descriptive statistics and t test were performed to assess the difference between the sides. Results: The transverse length and height of the vertebral body and width of the pedicle were increasing from C3 to C7 vertebrae. Pedicle width of C2 to C6 vertebrae was less than 5.0 mm. Medio-lateral diameter of foramen transversarium increased from C6 to C4 and then decreased from C4 to C1. Unilateral accessory foramen transversarium were observed frequently in C5 vertebra and more commonly on right side. Conclusion: Pedicle width of C2 to C6, which is crucial for the transpedicular screw fixation, was less than 5.0 mm indicating the need of smaller screws than the normal 3.5 mm screws. Least dimensions observed in C1 foramen transversarium could be a predisposing factor for vertebro-basilar insufficiency. Knowledge of cervical vertebral morphometry will help to reduce the complications and improve the outcome of cervical spine surgeries.

***Keywords*---**cervical vertebrae, foramen transversarium, morphometry, clinical implications.

Introduction

Cervical vertebrae are highly mobile part of the vertebral column. Mobility of cervical vertebrae makes them structurally weak and vulnerable for various injuries. Cervical vertebrae are unique that vertebral artery passes through the foramen transversarium present in their transverse process. The smaller size and complex anatomy of the cervical vertebrae make instrumentation difficult and adjacent neurovascular structures liable to be injured. Morphological studies on cervical vertebrae are conducted in different ways. Anatomical studies are carried out using the dry bones or cadavers. Radiological studies are carried out using Xray and CT images of the patients (pre and post operatively). High correlation was observed between the anatomical studies and radiological studies(1). Further, studies have shown significant difference in dimensions between different populations and sexes(1). Therefore, morphological studies of cervical vertebrae belonging to a particular population can give baseline information to the spine surgeons operating on that population to evaluate the feasibility and safety of surgical technique and usage of appropriate instrumentation. This information can be correlated with the preoperative CT images of the concerned patient and the surgeon can make the final decision.

In various pathological conditions like congenital malformations, carcinoma, trauma and degenerative diseases, the cervical spine is stabilized by arthrodesis. Cervical spine arthrodesis is achieved by various procedures involving anterior

plate, lateral mass screw, transpedicular screw, intralaminar screw and transfacet screw fixations(2). Collection of normal measurements of different components of cervical vertebra for a specific population will aid in the manufacture and selection of instrumentation suitable to that particular population(3). Dimensions of the vertebral body are helpful in surgical techniques like corpectomy, bicortical screw fixation and anterior plate fixation. Pedicular dimensions are beneficial during transpedicular screw fixation, which is considered to have a biomechanical advantage over lateral mass fixation and posterior hook or wire constructs. Further, transpedicular fixation has more pullout strength than the lateral mass fixation which would result in better surgical outcomes (4).

In all cervical spine surgeries, injury to the vertebral artery is the commonest complication. In addition, osteophytic changes around the foramen transversarium lead to vertebral artery dissection and predisposing to vertebrobasilar insufficiency (5). Therefore, the present study is an attempt to record the linear measurements of vertebral body, pedicle and foramen transversarium of all the cervical vertebrae in South Indian population. The measurements of body and pedicle were chosen because of their usefulness in anterior and transpedicular fixation procedures of cervical spine, which were commonly performed with great success and least complications. Measurements of foramen transversarium were selected in order to find its dimensions through which the vertebral artery passes through and to find vulnerability of vertebral artery being injured during cervical spine surgeries. The data obtained from this study would help in creating a baseline database, which could expound the normal values and variations of cervical spine in South Indian population.

Materials and Methods

The present study was conducted with the 138 cervical bones available in the bone collection of Anatomy department of our institute. The sex and age of the bones were unknown. Cervical vertebrae without any damage were included in the study. The cervical vertebrae were classified into typical and atypical varieties. The typical vertebrae were further classified into C3, C4, C5, and C6 based on the characters described by Frazer (6). The following metric parameters were studied using a digital vernier caliper with accuracy of 0.1 mm.

Vertebral body

Antero-posterior length: Distance measured between the anterior and posterior surfaces of the vertebral body in the midline. Transverse length: Maximum distance measured between the lateral surfaces of the vertebral body. Height: Distance between the superior and inferior surfaces of the body measured from anterior midline. These measurements were taken for C2 to C7 vertebrae.

Pedicle

Length: Distance between the superior articular process and vertebral body. Width: Distance measured between the medial and lateral surfaces of the pedicle. Height: Distance between the superior and inferior borders of the surfaces. These measurements were taken for C2 to C7 vertebrae.

Foramen transversarium

Antero-posterior and medio-lateral diameters of the foramen transversarium were measured for C1 - C7 vertebrae. Further, shape of the foramen transversarium and associated variations like absence or duplication were observed and recorded.

Statistical analysis

The data were presented as mean± standard deviation. The side difference between the parameters of pedicle and foramen transversarium were assessed using paired student t test using SPSS software (Version 21; IBM, USA). P value <0.05 was considered statistically significant.

Table1
Morphometry of the body of C2-C7 vertebrae

Vertebra	No.		Antero-posterior Length (mm)	Transverse Length (mm)	Height (mm)
C2	20	M±SD	13.85 ± 2.45	15.14 ± 2.79	16.47 ± 1.66
		Range	6.37-16.95	6.99-19.89	11.95-19.53
C3	10	M±SD	13.8 ± 1.53	17.53 ± 2.07	10.81 ± 1.63
		Range	10.57-16.32	13.65-19.78	7.41-12.94
C4	21	M±SD	16.04 ± 1.49	18.91 ± 1.61	11.1 ± 1.44
		Range	13.49-19.24	16.35-23.03	8.46-13.02
C5	20	M±SD	17.15± 2.17	19.88 ± 1.7	11.66 ± 1.65
		Range	13.12-21.54	18.01-23.06	9.96-16.74
C6	11	M±SD	16.94 ± 2.16	20.42 ± 1.77	10.64 ± 1.42
		Range	13.50-21.75	17.13-24.14	7.25-12.64
C7	32	M±SD	16.08 ± 1.96	24.69 ± 3.03	12.79 ± 1.27
		Range	13.08-21.28	19.68-33.17	9.90-15.24

M±SD – Mean ± Standard Deviation

Results

Vertebral body

The cervical vertebrae were classified and the numbers of each cervical vertebra employed in this study were C1- 14, C2 – 20, C3 – 10, C4 -21, C5 -20, C6 – 11 and C7 – 32. The measurements of the vertebral body are given in Table1. It can be appreciated that the transverse length of the body of the vertebra was gradually increasing from C2 to C7. The height of the vertebral body also showed a similar increase from C3to C7, except the height of C6, which was relatively smaller. Since the odontoid process was included in the measurement of height in C2 vertebrae, the measurements were higher than all the vertebrae. Anteroposterior length of the vertebral body did not show any increasing trend from C2 – C7, instead C5 had the maximum antero-posterior length (17.15 ± 2.17 mm) and C3 had the minimum antero-posterior length (13.8 ± 1.53 mm).

Pedicle

The measurements of the pedicle of the cervical vertebrae are given in Table 2. There were differences between the measurements of right and left side pedicles of every vertebra. However, the differences were not statistically significant. Pedicles with maximum length, width and height were observed in C6, C7 and C2 vertebrae respectively. Bilaterally pedicle width increased from C3 to C7. Length and height of the pedicle did not show any regular trend of increase or decrease in their dimensions as that of width. C6 had maximum pedicle length (Right side 6.29 mm and left side 6.14 mm) while maximum pedicle height was observed in C2 vertebra (right side 7.39 mm and left side 7.34 mm).

Table 2
Morphometry of the pedicle of C2-C7 vertebrae

Vertebra		Pedicle Length (in mm)		Pedicle Width (in mm)		Pedicle Height (in mm)	
		Right	Left	Right	Left	Right	Left
C2	M±SD	5.17 ± 0.98	5.48 ± 1.22	4.67 ± 1.6	4.29 ± 1.3	7.39 ± 1.32	7.34 ± 1.41
	Range	2.37-6.42	2.70-7.81	1.33-6.92	1.9-6.36	5.12-9.22	4.42-10.65
	P	0.197		0.093		0.898	
C3	M±SD	5.12 ± 1.29	5.27 ± 1.29	3.5 ± 1.17	3.43 ± 1.07	6.39 ± 1.53	6.38 ± 1.47
	Range	2.47-6.88	2.92-5.67	1.30-4.79	1.79-4.95	4.20-8.31	3.54-9.31
	P	0.547		0.755		0.983	
C4	M±SD	5.6 ± 0.68	5.31 ± 0.66	4.43 ± 0.81	4.32 ± 0.87	6.59 ± 1.05	6.83 ± 1.26
	Range	4.32-6.78	4.39-6.81	3.01-5.93	3.08-6.54	4.89-8.66	4.91-9.27
	P	0.860		0.538		0.158	
C5	M±SD	5.57 ± 0.72	5.47 ± 0.83	4.57 ± 0.88	5 ± 0.81	6.6 ± 1.12	6.64 ± 1.11
	Range	4.55-7.31	3.42-6.98	2.67-6.01	3.48-6.53	4.76-8.43	4.91-8.82
	P	0.639		0.054		0.839	
C6	M±SD	6.29 ± 0.76	6.14 ± 0.69	4.94 ± 0.54	5.11 ± 0.36	5.97 ± 0.98	6.18 ± 0.85
	Range	4.69-7.44	4.79-6.96	4.04-5.72	4.36-5.63	4.72-7.84	4.75-8.07
	P	0.510		0.442		0.305	
C7	M±SD	5.8 ± 0.79	5.85 ± 0.9	5.95 ± 1.07	6.05 ± 0.99	6.9 ± 0.98	6.93 ± 1.33
	Range	3.77-7.55	3.60-7.58	3.07-8.44	3.86-8.36	4.60-9.20	4.37-9.49

	P	0.754	0.523	0.818

M±SD – Mean ± Standard Deviation, P – Significance of Paired T-test statistics

Foramen transversarium

In both the sides, the antero-posterior and medio-lateral diameter of foramen transversarium was smallest in C1 vertebra (Table 3). Antero-posterior diameter of C7 foramen transversarium was smaller when compared to the C6 whereas its medio-lateral diameter was bigger than C6. It can be observed that the mediolateral diameter of foramen transversarium gradually increased from C6 to C4 and gradually decreased from C4 to C1 with C1 having the least diameter (Figure 1B) which was the course taken by the second part of the vertebral artery. Similar trend was not observed in the antero-posterior diameter. However, C1 had the least antero-posterior diameter (Figure 1A). Except C1 and C2, the medio-lateral diameter was larger than antero-posterior diameter in cervical vertebrae (Table 3). Regarding the shape of the foramen transversarium, oval shape was the commonest (90.9% - 100%) and round shape was found in 3.1% - 9.1% of the vertebrae (Table 4). The foramen transversarium was absent in one C5 vertebra on the right side (5%) (Figure 2A). Very small foramen transversarium were observed bilaterally on one C6 vertebra (Figure 2B). In one C2 vertebra, the superior articular facet was enlarged on left side. It was encroaching the foramen transversarium from the medial side (Figure 2C). Accessory foramen transversarium was more commonly observed on right side and was noticed in C1, C4, C5, C6 and C7 vertebrae (Figure 2D). The highest incidence of accessory foramen transversarium was seen in C5 vertebra (25%) followed by C6 vertebra (18.18%) and C7 vertebra (9.38%). Bilateral presence of accessory foramina was not noted (Table 4).

Table 3
Morphometry of the foramen transversarium

Vertebra		Antero-posterior Diameter (in mm)		Medio-lateral Diameter (In mm)	
		Right	Left	Right	Left
C1	M±SD	3.69 ± 0.57	3.66 ± 0.44	2.75 ± 0.43	2.98 ± 0.37
	Range	2.61-4.52	2.89-4.55	1.69-3.51	2.40-3.89
	P	0.827		0.164	
C2	M±SD	5.44 ± 1.16	5.16 ± 0.88	4.72 ± 1.07	4.93 ± 0.8
	Range	2.69-8.03	2.87-7.33	2.19-7.35	2.76-6.37
	P	0.210		0.327	
C3	M±SD	4.92 ± 1.39	5.35 ± 1.53	5.79 ± 1.13	6.09 ± 1.14
	Range	3.15-7.21	2.03-7.66	4.11-7.04	3.90-8.05
	P	0.334		0.381	
C4	M±SD	5.25 ± 0.59	5.29 ± 0.77	6.13 ± 0.74	6.19 ± 0.9

	Range	4.28-6.45	4.23-6.65	4.78-7.52	5.06-8.34
	P	0.831		0.706	
C5	M±SD	5.36 ± 1.24	5.18 ± 1.58	5.93 ± 1.24	5.51 ± 1.76
	Range	2.47-8.63	4.00-7.09	3.16-8.55	4.00-7.03
	P	0.714		0.451	
C6	M±SD	4.95 ± 1.4	5.48 ± 1.5	5.4 ± 1.67	5.44 ± 1.29
	Range	1.72-6.13	1.83-7.15	1.89-7.30	2.62-7.42
	P	0.180		0.933	
C7	M±SD	4.81 ± 1.44	4.53 ± 1.68	5.97 ± 2.16	5.5 ± 2.06
	Range	1.72-7.84	4.00-7.59	1.71-12.41	4.00-8.21
	P	0.470		0.372	

M±SD – Mean ± Standard Deviation, P – Significance of Paired T-test statistics

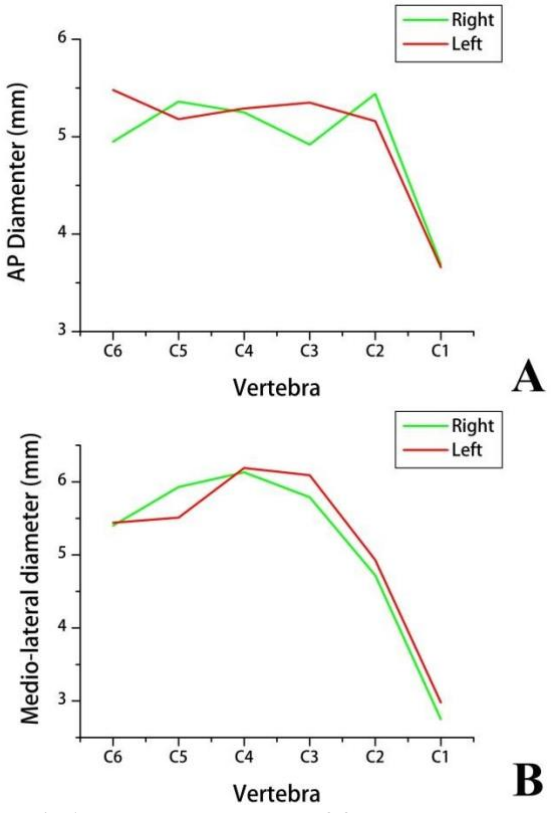

Figure 1. Changing trends in measurements of foramen transversarium. A- Shows the antero-posterior diameters of C6-C1 vertebrae and B – shows medio-lateral diameters of C6-C1 vertebrae. AP – Antero-posterior

Table 4
Foramen transversarium – Shape and accessory foramina

Vertebra	Shape					Accessory foramen transversarium			
	Right		Left			Right	%	Left	%
	Oval	Round	Oval	Round	Absent				
C1	14 (100%)		14 (100%)			1	7.14	1	7.14
C2	20 (100%)		19 (95%)	1 (5%)		Nil		Nil	
C3	10 (100%)		10 (100%)			Nil		Nil	
C4	21 (100%)		21 (100%)			1	4.76	1	4.76
C5	19 (95%)	1 (5%)	18 (90%)	1 (5%)	1 (5%)	5	25	Nil	
C6	10 (90.9%)	1 (9.1%)	10 (90.9%)	1 (9.1%)		2	18.18	Nil	
C7	31 (96.9%)	1 (3.1%)	31 (96.9%)	1 (3.1%)		3	9.38	3	9.38

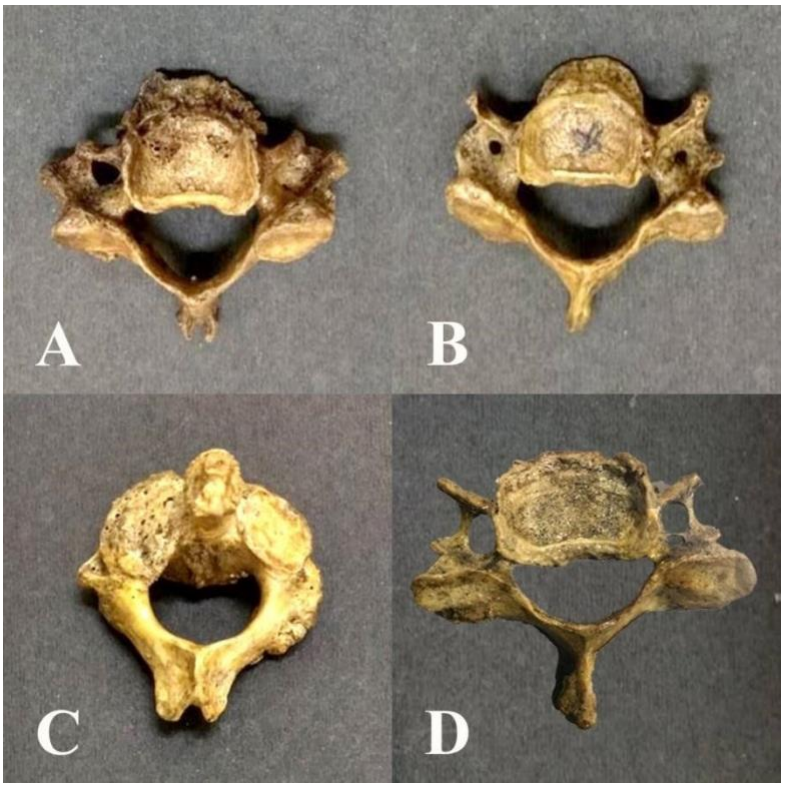

Figure 2. Variations in foramen transversarium. A – C5 showing absence of foramen transversarium on right side. B – C6 showing narrow foramina bilaterally. C – C2 showing enlarged superior articular facet encroaching left side foramen. D- C6 showing accessory foramen transversarium on right side.

Discussion

In this study, linear measurements of the dried cervical vertebrae C1 to C7 were attempted. The typical cervical vertebrae were classified according to the descriptions given by Frazer (6). Briefly, C3 and C4 vertebrae have their anterior tubercles of transverse process at a higher level than the posterior tubercle. The neural groove that is present lateral to the costo-transverse bar and between the anterior and posterior tubercles is deeper in C4 than C3. The anterior tubercles of C5 and C6 are at lower level than the posterior tubercles. Neural groove is wider in C5 and widest in C6 and the anterior tubercle of transverse process is larger in C6 forming the carotid tubercle. Most of the anatomical studies conducted on dry bones did not explicitly mention how the typical cervical vertebrae were classified (7, 8) or only the mean value of the parameters was mentioned taking into account all the typical vertebrae as single entity (9).

Vertebral body

Measurements of antero-posterior length and height of the vertebral bodies observed in the present study were similar to the results of work done by Prabavathy *et al.*(8) in South Indian population. In the present study, the transverse length was comparatively smaller. Transverse length and height of the body were increasing from C2 to C7 and from C3 to C7 vertebrae respectively in the present study. However, Prabavathy *et al.*(8) have reported an increase in transverse length

from C3 to C5 and height from C5 to C7. Results similar to the present study were reported by Saluja *et al.*(9) (Antero-posterior length 14.84 mm, transverse length 22.18 mm and height 11.39 mm). In all the studies, the transverse length was greater than the antero-posterior length of the vertebral body. Antero-posterior length and transverse length of the vertebral bodies are useful in procedures like corpectomy and bi-cortical screw fixation. Anteroposterior length helps the surgeon to estimate the distance between the anterior and posterior longitudinal ligaments. Transverse length expresses the lateral extent to which procedures can be performed on vertebral body without venturing into the nearby vertebral artery (3).

Pedicle

C2 vertebra: A CT study done by Pragash *et al.*(10) displayed the dimensions of pedicular width of C2 vertebrae (Right 4.99 mm and Left 5.20 mm) which were comparable with the present study. However, the height of the C2 pedicles (Right 4.79 mm and Left 4.75 mm) were significantly lower than the present study.
C3-C7 vertebrae: Study done in South Indian population by Nallan *et al.*(7) and Prabavathy *et al.*(8) showed that the pedicle length decreased from C3 to C5 vertebrae. Nallan *et al.*(7) reported that the width and height of the pedicle increased from C3 to C6 resembling the results of the present study. Prabavathy *et al.* reported decrease in the pedicle height from C3 to C7 (8). The present study exhibits no such regular pattern in the measurements of pedicle length and height. C6 vertebra has the maximum pedicle length in the present study and the study done by Nallan *et al.*(7).

A CT study done on 27 patients by Patwardhan *et al.*(11) has showed pedicle width increasing from C3 to C7 and the measurements were smaller in females. The minimum width was observed in C3 (5.1 mm) and the maximum width was observed in C7 (6.1 mm). Results were similar to that of the present study other than the sexual differences. For fixation of 3.5 mm pedicular screws, a minimum width of 5.0 mm is desired to avoid injury to the adjacent neurovascular structures (12). In the present study except the C7 vertebrae, all other vertebrae had the pedicle width less than 5.0 mm (Table 2). Results of Nallan *et al.*(7) concurred with the present study that except C6 (Right 5.17 mm and Left 5.16 mm), vertebrae C3 to C5 had width less than 5.0 mm. Saluja *et al.* and Patwardhan *et al.* had demonstrated that the mean dimensions of Indian cervical vertebral pedicles were relatively smaller when compared to the Western population(9, 11). The fact that Asian pedicular dimensions are smaller was substantiated by the review work done by Liu *et al.* (1). As a result, the present study shows usage of 3.5 mm pedicular screws might be not suitable in this population and 2.7 mm screws could be utilized as suggested by Patwardhan *et al.*(11).

Foramen transversarium

Foramen transversarium present in the transverse process of C1 to C6 cervical vertebra transmits vertebral artery, vertebral veins and sympathetic plexus. Vertebral vein and grey ramus of sympathetic ganglion pass through the foramen transversarium of C7 vertebra. The foramen may be subdivided in C5 and C6 with the small posterior foramen for the passage of vertebral vein and the anterior one for the passage of vertebral artery and sympathetic plexus. Subdivision in the form of bony spicules may be seen occasionally in other cervical vertebrae.(6) In the present study, similar subdivisions of foramen transversarium were observed in the

C1, C4, C5, C6 and C7 vertebrae with right side preponderance. Similar right-side preponderance of accessory foramen transversarium were reported by Rathnakar *et al.* and Dofe *et al.*(13, 14) Unfortunately, these two studies had not expressed the occurrence of accessory foramina in the individual typical vertebra. Bilateral occurrence of accessory foramen was not observed in the present study and its occurrence reported in literature was 1.42% and 15% (13, 14).

El Shaarawy *et al.* observed that accessory foramina were common at the lower cervical vertebra (C5, C6 and C7) and mostly in C6 (15). In accordance with their observations, in the current work, accessory foramen was frequently found in C5 vertebra (25%) followed by C6 vertebra (18.18%) (Table 4). Another study done by Sharma *et al.* on Indian population reported the incidence of accessory foramen transversarium in typical cervical vertebrae as C3 (0.5%), C4 (1.5%), C5 (2%) and C6 (4%) (16). Study done on atlas vertebrae by Sethi *et al.*(17) in North Indian population reported significantly higher dimensions of antero-posterior (Right 6.64 mm and Left 7.05 mm) and medio-lateral (Right 5.76 mm and Left 5.64 mm) diameters of foramen transversarium than the present study. It reported that 81.5% of the foramina were oval shaped. However, in the present study 100% of the foramina transversarium in atlas were oval shaped.

In the present study, we observed that the medio-lateral diameter of foramen transversarium is larger than antero-posterior diameter which is supported by a CT study on foramen transversarium done in Turkish population (18). The mediolateral diameter of foramen transversarium increased from C6 to C4 and then decreased from C4 to C1. Whereas, Tellioglu *et al.*(18) observed that the anteroposterior and medio-lateral diameters decreased from C1 to C7 vertebra. C1 vertebra had least antero-posterior and medio-lateral diameters of foramen transversarium indirectly indicating the decrease in the diameter of the vertebral artery as it travelled farther from its origin. This could be a probable cause for vertebral artery compression.

In the present study, one C5 vertebra had absence of foramen transversarium on right side and one C6 vertebrae had very narrow foramina bilaterally. This could possibly be due to entry of vertebral artery into the foramen transversarium at a higher level (like C5 or C4 either bilaterally or unilaterally). Being observed on dried bones, we were not able to ascertain the actual level of entry of vertebral artery. Conversely, if the vertebral artery entered at C6 level then narrow foramina will surely be a cause for compression of vertebral artery. The various shape and size of the foramen is attributed to the tortuosity and size of the vertebral artery (19). Size of the foramen transversarium is clinically relevant as osteophytic changes around the foramen may compress the vertebral artery leading to its dissection (20). Additionally, narrowing of vertebral artery may be the cause of formation of athreomatous plaques predisposing to vertebro-basilar insufficiency (5).

In all the studies quoted above including the present study, though there were differences between the dimensions of right and left side, the differences were not statistically significant. Variations between the studies indicate lack of uniformity in the dimensions of cervical vertebral parameters even within the Indian population. This warrants cautious preoperative assessment by the operating surgeon. Even after preoperative assessment, the surgeons shall take the help of 3D C-arm guidance and stealth navigation systems to place the screws and to perform successful cervical arthrodesis without neurovascular injury.

Conclusion

Linear measurements of body and pedicle of C2 to C7 cervical vertebrae were performed in this study. Pedicle width of C2 to C6 crucial for the screw fixation was less than 5.0 mm indicating the need of smaller transpedicular screws than the normal 3.5 mm screws. Least antero-posterior and medio-lateral diameters observed in foramen transversarium of C1 vertebrae could probably be a predisposing factor for vertebro-basilar insufficiency. Lack of similarity between the results of present study and the previous literature on Indian population warrants careful preoperative CT assessments for successful cervical spine surgeries. This data will be of much relevance to the anatomists, radiologists and surgeons working in the field of cervical spine. Knowledge of cervical vertebral morphometry will help to reduce the complications and improve the outcome of cervical spine surgeries.

Limitations

The sample size of individual vertebrae was smaller when compared to other studies. The vertebrae were of unequal numbers and their sex and age were unknown. Morphometry of lateral mass and lamina were not performed to give a comprehensive data useful for other types of fixations.

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Nil

Conflict of interest

There is no potential conflict of interest to declare.

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Figure legends

Figure 1: Changing trends in measurements of foramen transversarium. A- Shows the antero-posterior diameters of C6-C1 vertebrae and B – shows mediolateral diameters of C6-C1 vertebrae. AP – Antero-posterior

Figure 2: Variations in foramen transversarium. A – C5 showing absence of foramen transversarium on right side. B – C6 showing narrow foramina bilaterally. C – C2 showing enlarged superior articular facet encroaching left side foramen. D- C6 showing accessory foramen transversarium on right side.