Original Article

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Computed Tomography-Based Morphometric Analysis of Cervical Pedicle, Lateral Mass, and Cervical Facet in Subaxial Spine (C3-C7) to Assess Feasibility of Screw Fixation in Indian Population

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Abstract

Background: Posterior cervical spine fixation is indicated in the unstable cervical spine as a result of trauma, infection, degeneration, and neoplastic conditions. Laminar Wiring, lateral mass screw, pedicular screw, and recently transfacet screws are common methods; however, these techniques are associated with disastrous complications such as vertebral artery injury, spinal cord injury, nerve root damage facet, and pedicle breach. It is recommended to do thorough planning by doing a pre-operative computed tomography (CT) scan, especially for cervical pedicle screw insertion. A 3.5 mm diameter screw is commonly used which is based on the morphometric studies carried out in the western population, studies in Indian population have shown smaller sizes and dimensions in subaxial cervical spine. With this background, we undertook this study with an attempt to measure standard dimensions and also to actually measure the screw dimensions by adjusting the CT axes accordingly.

Methods: This cross-sectional study enrolled 50 patients (male and female) who were admitted to our institution for reasons other than cervical spine injury or complaints. All selected patient underwent CT scan of the cervical spine in our institute. A CT scan-based attempt was made to measure the exact length and diameter of screw required for lateral mass, cervical pedicle, and transfacet fixation at each level of subaxial spine (C3-7) by adjusting the axes to mimic three-dimensional form, not earlier attempted in literature. CT cuts are taken parallel to the upper endplate of the vertebral body using helical CT scanner at 2.5 mm intervals. Nine important parameter dimensions have been calculated. Measurement is taken both for right and left side pedicle axis length (PAL), pedicle length plus lateral mass length, pedicle width (PW), pedicle height (PH), lateral mass longitudinal diameter, lateral mass transverse diameter, lateral mass height, lateral mass screw length, and transfacet screw length.

Results: Our results are in agreement with the majority of studies that there is no difference between right and left side values. Mean values of PW progressively increasing for both male and female from C3 to C7 level, also it is found that female has smaller value compare to male. PH in the sagittal plane is found to be larger than PW, at each vertebral level, and for both male and female. Hence, PW should be important parameter to determine pedicle screw size. PAL is found to be progressively increasing from C3 to C7 for both male and female, but pedicle length is found to increasing from C3 to C6, and slightly decreasing at C7 vertebral level. The study also shows that dimension of subaxial cervical vertebrae is smaller than western population.

Conclusions: As the difference is found between sex, level, and ethical variation, pre-operative CT should be performed to know the dimension of cervical vertebrae to avoid complication.

Key words: Cervical Pedicle, Computed Tomography, Spine

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INTRODUCTION

The cervical spine consists of seven vertebrae joined by an intervertebral disc. Third to seventh cervical vertebra (C3-C7) are named as subaxial cervical spine. The first and second vertebrae are atypical since each possesses specific feature for self-identification.

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The cervical spine instability caused by fracture, deformity or degenerative disease is treated with neurovascular decompression, anatomic reduction, rigid spinal fixation, solid fusion, and early rehabilitation. Anterior fixation (stabilization) of the cervical spine includes anterior cervical plating with screws and cages; posterior fixation includes posterior cervical wiring, laminar screw fixation, lateral mass screw fixation, pedicle screw, and transfacet screw fixation with their merit and demerit.[1-5]

Roy - Camille first introduced lateral mass screw fixation provide strong posterior fixation useful in patients whose pedicle and lamina are deficient. Lateral mass screw fixation is contraindicated in any traumatic or pathological process that compromises the integrity of the lateral mass.[2] Pedicle screws in cervical spine offer superior fixation, with a high complication rate of the vertebral artery and cord injury.[6] Transfacet screws are lag screws that do not require a rod to immobilize the spine. This technique can be used for percutaneous fixation. To use this technique percutaneous placement, anatomical parameter data are needed.[7]

Pre-operative computed tomography (CT) is recommended for a quantitative understanding of subaxial cervical spine morphology for pedicle screw fixation, lateral mass, and transfacet screw fixation to improve accuracy and minimize complication which includes vertebral artery injury, spinal cord injury, and nerve root injury.

Differences in cervical spine morphology have been reported across different study population.[8] Some studies also reported that sex, race, and geographic occurrence play a significant role in cervical anatomy, Asians trends to be smaller than Europeans and Americans. Female has smaller pedicle than male.[9] The morphology of cervical spine has been studied extensively using both cadavers and CT films; however, CT scan provides the most accurate rendering of anatomy for assessing the accuracy of screw placement.[10]

The data regarding CT based morphometric measurement of the cervical spine are focused on Caucasian population. Indian studies are mainly focused on thoracic and lumbar spine. Very few studies have been done to study the morphology of cervical spine in relation to screw placement.

The objective of this study was to determine morphometric characteristics of subaxial cervical spine in Indian population to assess the feasibility of screws fixation in pedicle, lateral mass, and transfacet. A CT scan-based attempt was made to measure the exact length and diameter of screw required for lateral mass, cervical pedicle, and transfacet fixation at each level of subaxial spine (C3-7) by adjusting the axes to mimic the three-dimensional form, not earlier attempted in literature.

MATERIALS AND METHODS

This cross-sectional study enrolled 50 patients (male and female) who were admitted to our institution for reasons other than cervical spine injury or complaints. Approval from hospital ethics committee was taken to conduct this study. Patients were enrolled after obtaining written, informed consent.

The inclusion criteria of selected patients were - non-pregnant females, age between 18 and 35, and trauma other than cervical. Following were the exclusion criteria - patients with poor general conditions, patients with cervical spine trauma/tumor/pathology, pregnant females, and congenital anomaly of spine.

All selected patient underwent CT scan of the cervical spine in our institute. CT was performed with patient supine and neck at the neutral position. CT scan of the patients was studied and measurement of that parameter which is considered to be significant for assessing the feasibility of screw fixation done. A CT scan-based attempt was made to measure the exact length and diameter of screw required for lateral mass, cervical pedicle, and transfacet fixation at each level of subaxial spine (C3-7) by adjusting the axes to mimic the three-dimensional form, not earlier attempted in literature. CT cuts are taken parallel to the upper endplate of the vertebral body using helical CT scanner at 2.5 mm intervals.

Nine important parameter dimensions have been calculated. Measurement is taken both for right and left side.

1. Pedicle axis length (PAL) - Distance from the posterior cortex of the pedicle axis projection on lateral mass to the anterior margin of the vertebral body.
2. Pedicle length plus lateral mass length - Distance from the posterior cortex of the pedicle axis projection on lateral mass to the junction of the vertebral body.
3. Pedicle width (PW) - Medio-lateral diameter of pedicle isthmus at the narrowest point.
4. Pedicle height (PH) - Superoinferior diameter of pedicle isthmus on sagittal cuts.
5. Lateral mass longitudinal diameter (LMLD) - Which is the distance from the posterior cortex of the lateral mass to the posterior edge of the transverse foramen.
6. Lateral mass transverse diameter (LMTD) - Which is the distance from lateral cortex of the lateral mass to the medial edge of the osseous spinal canal.
7. Lateral mass height (LMH) - Sagittal height as considered as the anatomical height at the center of lateral mass.

8. Lateral mass screw length (LMSL) - Three fixed parameters were used for measuring LMSL - (1) The point of screw insertion was the midpoint of the lateral mass. It was crossing point between the sagittal and axial planes of lateral mass, (2) the direction of screw in craniocaudal plane was 30° to avoid facet joint penetration, and (3) the exist point of screw was located on ventral cortex of lateral mass just lateral to roof transverse process in mid-axial cut of each lateral mass to make a sound bicortical fixation without injuring the vertebral artery of nerve root.
9. Transfacet screw length (TSL) - On reconstructed sagittal images to determine screw length trajectory perpendicular to facet joint in cephalocaudal direction, screw length was measured from midpoint of the facet to ventral cortex of facet below immediately adjacent to vertebral artery foramen.

Statistical Analysis

Data obtained were analyzed using statistical package for the social sciences (SPSS) software version 20 for Windows (SPSS). All the results were expressed as mean, standard deviation and $P < 0.05$ was considered as significant. Unpaired *t*-test was used determine any significant difference in parameter, according to sex and side and level.

RESULTS

A present cross-sectional study comprises 50 patient studies of this 29 were male and 21 were female. All selected patient underwent routine CT in our institute from July 2015 to November 2017. The mean age of males (30.5 years) and females (30.29 years) was similar. There were 29 (58%) males and 21 (42%) females in the study.

PW and PH

On application of unpaired *t*-test, there was a significant difference between male and female individual cervical vertebrae except PW of both sides in third and fourth cervical vertebrae and left side PW of fifth cervical vertebrae among study subjects. There was no significant difference between the vertebral dimensions of left and right sides of individual cervical vertebra among the study subjects.

Mean PW progressively increase from C3 to C7. The mean value for females is smaller than males for both left and right sides. Highest value found at C7 and lowest at C3. C3 and C4 PW, especially in female population, was <5 mm. Mean PH has been found to be progressively increasing from C3 to C7 vertebrae level. The mean value for females is smaller than males. However, the difference between left and right sides is very little for both male and female. Value of PH is found to be larger than PW at each level and in both sex, so for planning pedicle screw size attention should be given especially on PW [Table 1, Figures 1 and 2].

Pedicle Length Plus Lateral Mass Length

Increase from C3 to C6 slightly decrease at C7 for both male and female. Highest value of pedicle length plus lateral mass at C6 Level.

Table 1: Pedicle width and height (mm) of studied part (mean±SD)

Level	Sex	Pedicle width		Pedicle height	
		Right	Left	Right	Left
C3	Male	4.91±0.52	4.95±0.54	6.27±0.45	6.28±0.44
	Female	4.59±0.75	4.67±0.80	5.67±0.57	5.62±0.59
C4	Male	5.0±0.49	5.05±0.53	6.40±0.40	6.39±0.37
	Female	4.75±0.60	4.67±0.69	5.85±0.52	5.80±0.55
C5	Male	5.29±0.47	5.27±0.43	6.56±0.39	6.66±0.44
	Female	4.95±0.57	5.06±0.63	6.06±0.46	6.08±0.52
C6	Male	5.52±0.48	5.48±0.49	6.54±0.43	6.53±0.41
	Female	5.16±0.47	5.20±0.44	6.11±0.49	6.14±0.58
C7	Male	5.90±0.52	5.9±0.62	6.71±0.42	6.66±0.44
	Female	5.50±0.43	5.53±0.53	6.31±0.47	6.33±0.43

SD: Standard deviation

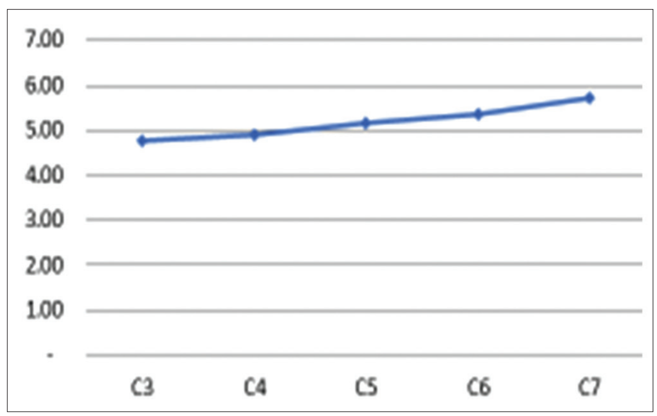

Figure 1: Line diagram sowing nature of variation of pedicle width vertebrae wise

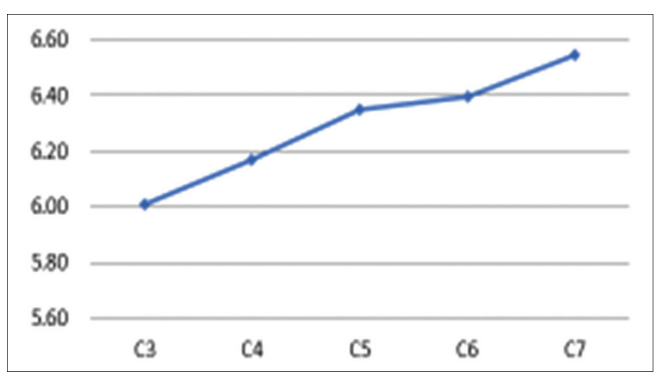

Figure 2: Line diagram sowing nature of variation of pedicle height vertebrae wise

PAL

Progressively increasing from C3 to C7 both for male and female. Female has a smaller value than male [Table 2, Figures 3 and 4].

Table 2: Dimension of pedicle length plus lateral mass and pedicle axis length (mean±SD)

Level	Sex	Pedicle and lateral mass length		Pedicle axis length	
		Right	Left	Right	Left
C3	Male	15.56±1.96	15.64±1.93	28.35±1.93	28.26±1.90
	Female	14.05±1.07	14.07±1.12	26.69±1.41	26.47±1.56
C4	Male	15.98±2.03	15.95±2.04	28.75±1.68	28.62±1.71
	Female	14.21±0.97	14.24±0.90	27.03±1.93	26.38±1.85
C5	Male	16.61±2.21	16.60±2.24	29.45±1.73	29.36±1.94
	Female	14.78±1.03	14.79±1.0	27.55±1.72	27.36±1.94
C6	Male	16.90±2.65	16.91±2.62	30.20±1.79	30.15±1.71
	Female	14.92±0.99	15.00±0.98	27.83±1.70	27.74±1.83
C7	Male	15.94±2.27	15.82±2.85	30.98±1.74	30.97±1.74
	Female	14.62±1.02	14.32±1.11	28.55±1.47	28.93±1.75

SD: Standard deviation

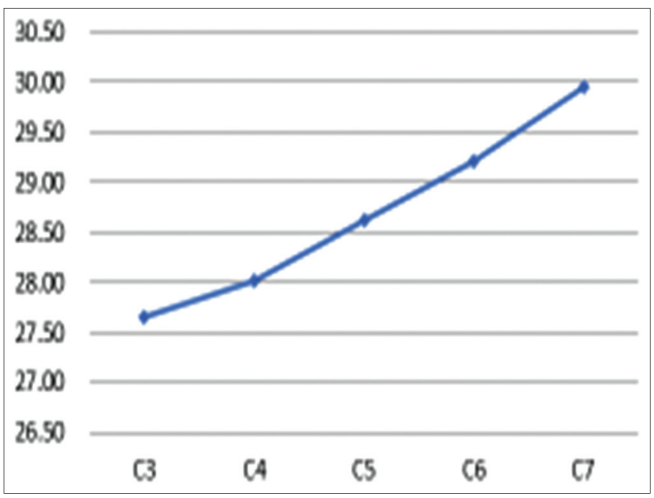

Figure 3: Line diagram sowing nature of variation of pedicle axis length vertebrae wise

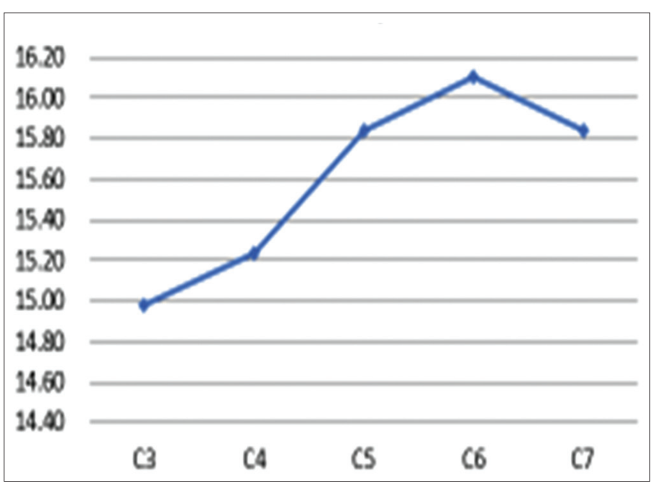

Figure 4: Line diagram sowing nature of variation of pedicle length vertebrae wise

LMTD and LMLD

C6 had larger transverse and longitudinal diameter measurement than other vertebrae. C7 has a minimum longitudinal diameter, and C3 has a minimum transverse diameter [Table 3, Figures 5 and 6].

LMH

There was a minimum difference of LMH between each vertebral level, C7 has a higher value compared to another level. Showing that there was no significant difference

Table 3: Dimension of LMTD and LMLD (mean±SD)

Level	Sex	Tranverse diameter (mm)		Longitudinal diameter (mm)	
		Right	Left	Right	Left
C3	Male	12.88±0.95	12.89±0.97	11.97±1.00	11.94±1.01
	Female	11.23±0.55	11.12±0.59	10.53±0.50	10.50±0.49
C4	Male	12.85±0.95	12.78±0.59	12.07±0.90	12.06±0.90
	Female	11.29±0.47	11.26±0.49	10.58±0.50	10.06±0.43
C5	Male	13.42±0.97	13.12±0.98	12.60±0.93	12.64±0.96
	Female	11.72±0.59	11.70±0.57	10.88±0.53	10.97±0.49
C6	Male	13.51±0.98	13.32±0.99	12.78±0.83	12.77±0.88
	Female	11.87±0.58	11.88±0.60	11.09±0.43	11.14±0.50
C7	Male	13.06±0.8	12.96±0.88	11.82±0.92	11.83±0.85
	Female	11.58±0.51	11.56±0.51	10.51±0.60	10.6±0.67

LMTD: Lateral mass transverse diameter, LMLD: Lateral mass longitudinal diameter, SD: Standard deviation

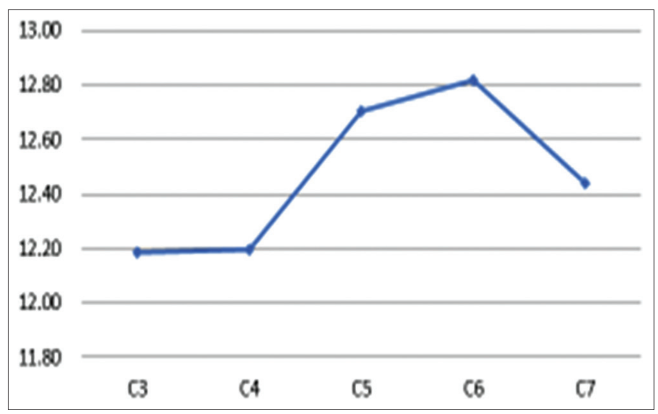

Figure 5: Line diagram showing variation of lateral mass transverse diameter vertebrae wise

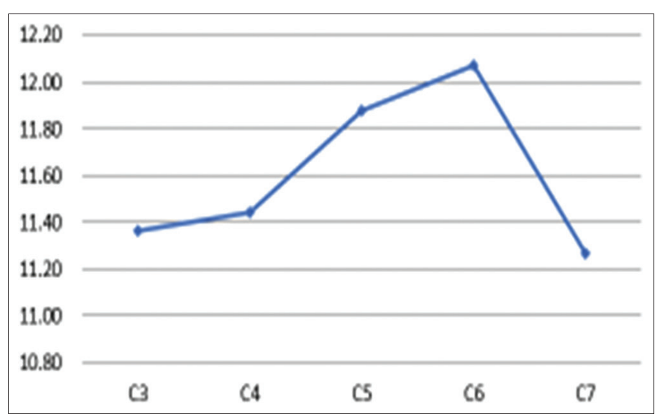

Figure 6: Line diagram showing lateral mass longitudinal diameter vertebrae wise

of LMSL between C3 and C6 but value decrease at C7. Maximum screw length found to be at a C6 level and minimum value at C7 level [Table 4, Figures 7 and 8].

TSL

Decrease as one moves to lower levels of the cervical spine. Female has lower value compare to male. Maximum screw length found at C3-C4 level, and minimum value at C6-C7 [Table 5 and Figure 9].

Table 4: Dimension of LMH and screw length (mean±SD)

Level	Sex	Lateral mass height (mm)		Lateral mass screw length (mm)	
		Right	Left	Right	Left
C3	Male	11.70±1.16	11.69±1.16	12.88±0.93	12.86±0.94
	Female	10.11±0.30	10.21±0.55	11.21±0.55	11.89±0.71
C4	Male	11.71±1.12	11.71±1.10	12.91±0.91	12.91±0.91
	Female	10.10±0.34	10.20±0.58	11.88±0.73	11.91±0.70
C5	Male	12.10±0.93	12.09±1.14	13.15±0.98	13.11±0.97
	Female	10.43±0.48	10.46±0.53	12.12±0.80	12.16±0.73
C6	Male	12.08±1.14	12.07±1.14	13.40±0.93	13.41±0.93
	Female	10.45±0.48	10.49±0.53	12.40±0.81	12.49±0.80
C7	Male	11.91±1.07	11.90±1.07	12.26±1.06	12.33±1.11
	Female	10.11±0.39	10.21±0.52	10.89±0.97	11.05±1.03

LMH: Lateral mass height, SD: Standard deviation

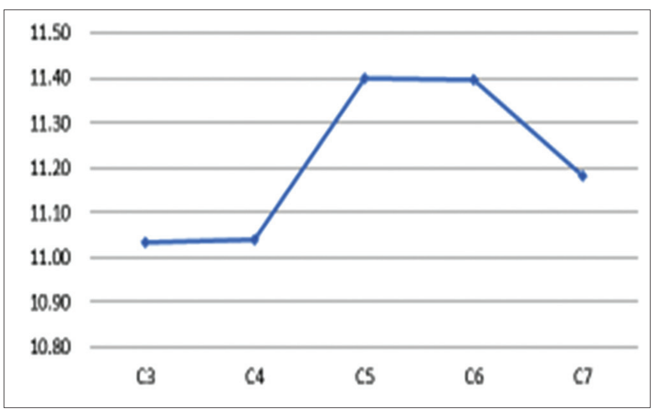

Figure 7: Line diagram showing variation of lateral mass height

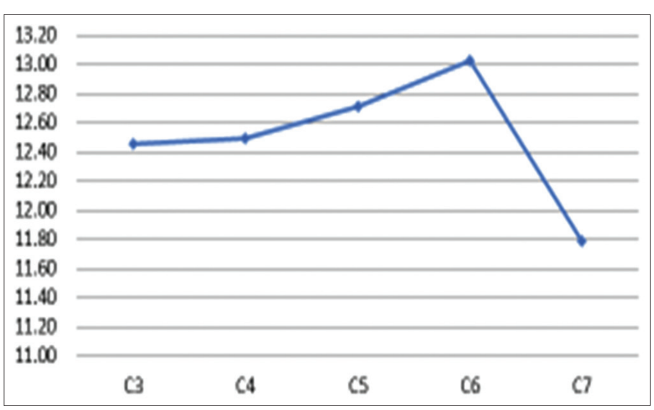

Figure 8: Line diagram showing variation of lateral mass screw length

DISCUSSION

Posterior fixation of the cervical spine is commonly performed for cervical spine instability; four common fixation techniques are posterior cervical wiring, laminar screw, lateral mass screw fixation, and pedicle screw fixation. New method alternative to lateral mass fixation is transfacet fixation.[7]

Abumi *et al.* first described a technique for pedicle screw fixation in 1994.[4] The starting point was 1 mm lateral to the center of articular mass, near the cranial end of the superior articular process. A high-speed burr is used to decorticate the starting point to expose the pedicle canal. A probe is then inserted into the canal with the help of image intensifier. The pedicle is tapped finally an appropriately sized screw is inserted. Complication associated with pedicle screw fixation is an injury to the vertebral artery, spinal cord, or exiting nerves. The main complication can be minimized with appropriate pre-operative imaging. Pre-operative cervical CT scan should be done to assess pedicle morphology therefore safe subaxial cervical pedicle screw placement requires instruction and appropriate supervision from experienced surgeons.

Table 5: Dimension of transfacet screw length in mean and SD

Level	Sex	Transfacet screw length (mm)	
		Right	Left
C3-C4	Male	17.77±1.78	17.73±1.79
	Female	15.06±1.79	15.02±1.80
C4-C5	Male	17.44±1.78	17.43±1.80
	Female	14.74±1.83	14.70±1.85
C5-C6	Male	16.36±1.82	16.36±1.83
	Female	14.12±1.67	13.98±1.68
C6-C7	Male	13.37±1.67	13.32±1.69
	Female	11.53±1.57	11.50±1.56

SD: Standard deviation

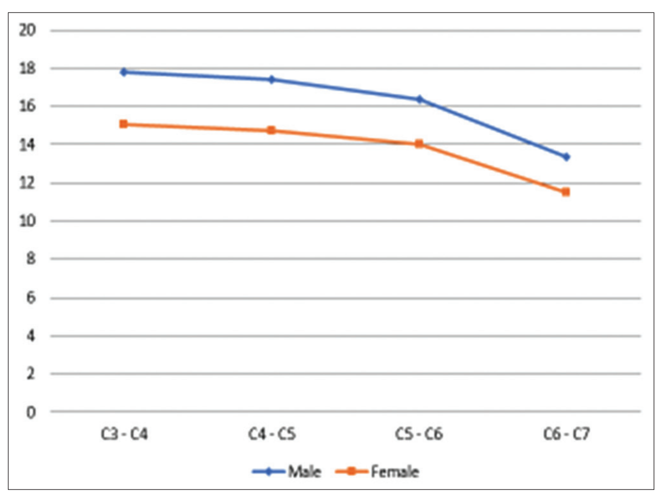

Figure 9: Line diagram showing variation of transfacet screw length

Roy - Camile first introduced lateral mass fixation technique[2] the starting point for Roy -Camille technique is at the midpoint of lateral mass. An entry hole is created using 2 mm drill bit, angling perpendicular to posterior lateral mass 10-degree lateral to the sagittal plane. Next, the drill hole is tapped with 3.5 mm tap, and probe is inserted to measure the screw length, and appropriate size screw is inserted. Lateral mass fixation is common and safe technique than transpedicular screw fixation; however, misplacement of lateral mass screws can cause injury to the spinal cord, vertebral artery, spinal nerves, and facet joint.

Transfacet fixation,[7] technique originally described by Takayasu *et al.*[5] the facet screw is lag screw that does not require a rod to immobilize. Technique of transfacet screw fixation - with the patient in prone position, posterior exposure of the cervical spine is done. The entry point is 2 mm above the middle of the lateral mass without any lateral angulation. Under fluoroscopic guidance, the facet is drilled until all the four cortical surfaces are purchased. Then, the depth is measured to assess the length of the screw required. This is followed by tapping and screw insertion both of which are done under fluoroscopic control. All screws are placed before laminectomy to decompress the cervical cord.

Pre-operative CT study is crucial for avoiding complications during surgeries. Various studies conducted on the western population have shown the dimension of subaxial cervical spine was adequate for a 3.5 mm screw.[11] Singh *et al.* studied Indian population in the mid-thoracic region, found that smallest diameter screw and shortest available screw may not be safe in the majority of Indian population.[12]

Few CT based studies are done on Indian population to study the morphology of cervical spine.[13] This study was done to understand the morphology of subaxial cervical spine to assess the feasibility of screw fixation.

In the present study, 50 patients CT of subaxial cervical spine has been done for measuring the selected anatomical parameter. The results of our study were compared with earlier morphological studies.

In CT comparison with the western population, PW is smaller in Indian population. However, the previous study done on Indian population PW, the resulting values are very close to present study.

Ludwing *et al.* demonstrated that if pedicle diameter in cervical spine was >5.0 mm 79% were pedicle, 19% had non-critical breeches, and only 2% had critical breach.[11] thus if 3.5 mm pedicle screw is to be inserted into the cervical pedicle, the minimum PW desired is 5 mm to allow at least 0.75 mm bony bridge medially and laterally to avoid injury to the adjacent vital structure.

In our study, especially in female population PW at C3, C4 level is found to be <5.0 mm so if we use the 3.5 mm chance of neurovascular injury is high.

Table 6 value shows that each pedicle may differ individually, so the dimension of screw should be measured at each level.

In CT comparison with the western population PH is smaller in Indian population. However, a study done on Indian population PH, the resulting values are very close to present study. Similar trend found regarding the progressive increase in value from C3 to C7 level [Table 7].

Pedicle dimension of Indian population found to be smaller than western population. Thus, this smaller size of pedicle is taken into account for planning a surgical procedure.

Lateral mass length and pedicle length and PAL are important measurement for correct and controlled pedicle screw length. There is the very small difference between each vertebral level. Value of pedicle length increase from C3 to C6 level and decrease at C7 level [Table 8].

As shown in table value of PAL progressively increase from C3 to C7 level [Table 9].

Table 6: Comparisons of previous and present measurement of PW of cervical vertebrae

Study (years)	PW (mean, in mm)				
	C3 level	C4 level	C5 level	C6 level	C7 level
Rao *et al.*[14]	5.3	5.3	5.75	6.1	7.05
Liu *et al.*[9]	5.26	5.33	5.68	5.91	6.64
Banerjee *et al.*[15]	4.89	4.87	5.09	5.42	6.19
Patwardhan *et al.* (2015)[13]	5.2	4.95	5.15	5.45	5.85
Asadhi *et al.*[16]	4.62	4.57	4.8	5.09	6.60
Present study	4.75	4.81	5.12	5.34	5.70

PW: Pedicle width

Table 7: Comparison of previous and present measurement of PH of cervical vertebrae

Study (years)	PH (mean, in mm)				
	C3 level	C4 level	C5 level	C6 level	C7 level
Ugur *et al.*[17]	6.3	6.5	6.4	6.6	NA
Panjabi *et al.* (2003)[18]	6.7	7.1	6.3	6.2	NA
Liu *et al.*[9]	6.7	6.78	6.95	7.25	7.63
Banerjee *et al.* (2010)[15]	6.66	6.69	6.95	6.43	6.75
Asadhi *et al.*[16]	6.32	5.99	6.17	6.14	6.39
Present study	5.99	6.12	6.31	6.32	6.51

PW: Pedicle width

Table 8: Comparison of previous and present measurement of pedicle length and lateral mass of cervical vertebrae

Study (years)	Pedicle length±lateral mass length (mean in mm)				
	C3 level	C4 level	C5 level	C6 level	C7 level
Liu *et al.*[9]	16.8	15.6	16.3	16.2	16.4
Banerjee *et al*. (2010)[15]	15.06	15.50	16.64	16.96	15.84
Present study	15.77	15.69	15.91	15.97	15.38

Table 9: Comparisons of previous and present measurement of PAL of cervical vertebrae

Study (years)	PAL				
	C3 level	C4 level	C5 level	C6 level	C7 level
Liu *et al.*[9]	29.9	28.9	31.3	31.2	32.5
Banerjee *et al*. (2010)[15]	28.72	28.77	30.51	31.92	32.79
Present study	27.52	27.89	28.50	29.02	29.76

PAL: Pedicle axis length

Table 10: Comparisons of previous and present measurement of LMTD of cervical vertebrae

Study (years)	LMTD (mean, in mm)				
	C3 level	C4 level	C5 level	C6 level	C7 level
Wang *et al.*[19]	12.25	12.15	12.70	12.60	12.62
Present study	12.05	12.07	12.57	12.66	12.36

LMTD: Lateral mass transverse diameter

There was some difference between current study and Wang *et al*. study regarding maximum and minimum transverse diameter of lateral mass.

The highest value of LMTD found at C5 level in Wang *et al*. study; in our study, it is at C6 level [Tables 10 and 11].

Our results are in agreement with the majority of studies that there is no difference between right and left sides values. Mean values of PW progressively increasing for both male and female from C3 to C7 level, also it is found that female has smaller value compared to male [Table 12].

PH in the sagittal plane is found to be larger than PW, at each vertebral level, and for both male and female. Hence, PW should be important parameter to determine pedicle screw size. PAL is found to be progressively increasing from C3 to C7 for both male and female, but pedicle length is found to increasing from C3 to C6, and slightly decreasing at C7 vertebral level. The study also shows that dimension of subaxial cervical vertebrae is smaller than western population. As the difference is found between sex, level, and ethical variation, pre-operative CT should be performed to know the dimension of cervical vertebrae to avoid complication.

Table 11: Comparisons of previous and present measurement of LMTD of cervical vertebrae

Study (years)	LMLD (mean, in mm)				
	C3 level	C4 level	C5 level	C6 level	C7 level
Wang *et al.*[19]	11.90	11.75	12.60	13.25	10.65
Present study	11.25	11.37	11.74	11.96	11.16

LMLD: Lateral mass transverse diameter

Table 12: Comparisons of previous and present measurement of TSL of cervical vertebrae

Study (years)	TSL (mean in mm)			
	C3-C4	C4-C5	C5-C6	C6-C7
Milchteim *et al.*[20]	17.9	15.87	16.25	13.05
Present study	16.42	16.09	15.23	12.34

TSL: Transfacet screw length

Limitations of the study are study population (*n* = 50) which may not be large enough to generalize the results to the greater population, but it provides useful information regarding the morphometric variation of subaxial cervical vertebrae in Indian population.

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