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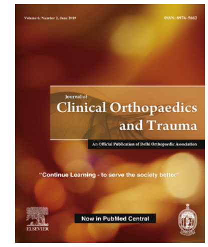

Original Article

Computed tomographic-based morphometric study of thoracic spine and its relevance to anaesthetic and spinal surgical procedures

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ABSTRACT

Background: To collect a baseline computer software aided normative morphometric data of thoracic spine in the Indian population and analyze it to give pre-procedural guidelines to clinicians for safe surgical and anaesthetic procedures in the thoracic spine.

Methods: CT scans of thoracic spine of patients free from spinal disorders were reviewed in a total of 600 vertebrae in 50 patients. Parameters recorded with the help of computer software were pedicle width, length and height, transverse pedicle angles, chord length, canal dimensions, body width and height, spinous process angle and transverse process length.

Results: Pedicle width decreased from T1 (9.27 ± 1.01) to T4 (4.5 ± 0.93) and increased to T12 (8.31 ± 1.83). At T4 76% and at T5 62% of the pedicles were smaller than 5 mm and would not accept 4 mm screw with 1.0-mm clearance. However, at T1 2%, at T11 7% and at T12 8% would not accept a 4 mm screw. Chord length gradually increased in upper thoracic vertebrae and was relatively constant in middle and decreased in lower thoracic vertebrae. Shortest estimated chord length was at T1 (30.30 ± 2.11). On an average, from T1 to T6 and at T11 and T12, a screw length of 25–30 mm could be accommodated and from T7 to T10, 30–35 mm screw length could be accommodated. Transverse pedicle angle decreased from T1 (35.4 ± 2.21) to T12 (-9.8 ± 2.39). Canal dimensions were narrowest at T4/T5 (20.02 ± 1.23) in anteroposterior and 21.12 ± 1.23 in interpedicular diameters. Spinous process angle increased from T1 (30.11 ± 6.74) to T6 (57.89 ± 9.31) and decreased to 16.21 ± 7.38 at T12. Transverse process length increased from T1 to T7 ($23.54 + 2.12$ to $31.21 + 1.91$) and then decreased to $12.11 + 2.3$ at T12. Vertebral body dimensions showed increasing trends from T1 to T12.

Conclusions: A thorough knowledge of anatomical and radiological characteristics of the spine and their variations is essential for the clinicians. Data collected in the present study

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provides baseline normative values in Indian population and will help in guiding safe and effective completion of both surgical and anaesthetic procedures in the thoracic spine. Computer software aided morphometric data can help in selecting appropriate size and optimal placement of the implant with minimal procedural difficulties and complications during spine surgery.

1. Introduction

Vertebral column comprising spine and spinal cord is one of the most complex structures of human body. Thoracic part of vertebral column is even more complex with two end segments appearing to be transitional zones towards cervical (T1–T3) and lumbar (T9–T12) region and the middle zone is of utmost importance due to the presence of combination of narrow spinal canal and critical vascular supply.[1–4] Knowledge of morphology of the thoracic spine is essential for the anaesthetic and surgical procedures carried out in this part of the vertebral column, to achieve desired results and to avoid complications.

The thoracic epidural has been widely used for the purposes of anaesthesia and analgesia. Injection into this space can be given as a single shot, intermittent, continuous or under the control of the patient (patient-controlled epidural analgesia (PCEA)). Intermittent or continuous injections into the space are carried out through an epidural catheter. Epidural injection of corticosteroids is one of the most commonly used interventions in managing radicular pain caused by nerve irritation.[5] Thoracic epidural anaesthesia (TEA) followed by postoperative epidural analgesia is increasingly being used for thoracic, upper abdominal, major vascular and cardiothoracic surgery. The objective of thoracic block is not solely to block noxious afferent stimuli from the surgical site, but to impart a bilateral selective thoracic sympathectomy. It is also used for pain management in conditions associated with chronic pain.[6]

The advent and general acceptance of pedicle screw fixation of thoracic spine has made the morphometric analysis of the thoracic pedicle a clinical necessity for all the surgeons practicing this procedure.[7] There are lots of studies that have been conducted on morphometry of thoracic spine using cadaveric specimen either directly or radiographically.[1,8–23] But only few studies, especially in Indian population, have been carried out to quantify thoracic spine morphometric data on CT scanning, the gold-standard for preoperative planning.[1,24–33]

This study aims at collecting and analyzing the morphometry of thoracic spine in a detailed manner in Indian population and comparing with available literature.

2. Materials and methods

This is a prospective study of thoracic morphometric data from 50 patients aged more than 20 years; who underwent CT thorax for other pathologies and were free from spinal disorders. Prior informed consent from the patients was taken. A total of 600 vertebrae were studied from patients of either sex. All the measurements were made directly from the scanner software of the Siemens Somatom Volume Zoom 4 Plus scanner using bone window setting. Axial sections were taken at a 4-mm interval. All the measurements were made by the same investigator to avoid interobserver discrepancy. Using the bone window, the cut section of CT where the right and left pedicles appear largest was selected for the pedicle, canal and transverse process dimensions measurements. Mid-sagittal section of the thoracic spine was used to measure vertebral body dimensions and spinous process angle.

The following measurements were made:

1. Transverse pedicle isthmus width (TPIW): Pedicle's narrowest diameter in transverse plain along the transverse pedicle axis.
2. Pedicle length: measured as the distance along the line drawn from the flattest portion of the posterior cortex of lamina to the posterior cortex of vertebral body along the line parallel to the pedicle longitudinal axis.
3. Transverse pedicle angle (TPA): obtained by measuring the angle between the AP midline axis and the pedicle longitudinal axis.
4. Chord length: measured as the distance along the line drawn from the flattest portion of the posterior cortex of lamina to the anterior cortex of vertebral body along the line parallel to the pedicle longitudinal axis.
5. Canal dimensions: Canal dimensions were measured both in anteroposterior (APD) and interpedicular distance (IPD).
6. Vertebral body width (VBW): The width of vertebral body at middle of the body.
7. Vertebral body height (VBH): Distance between superior and inferior end plates was measured both anteriorly (VBHa) and posteriorly (VBHp).
8. Transverse process length (TPL): Measured from base to tip of the transverse process.
9. Spinous process angle (SPA): Angulation of the spinous process in the sagittal plane.

Collected data were analyzed and compared with other studies.

3. Results

3.1. Patient demographics

Fifty scans from 28 men and 22 women were selected for review in the present study. The mean age was 39.27 ± 14.65 years (range from 20 to 70 years). No significant difference was

Table 1 – Tabulated data of pedicle and vertebral canal dimensions in the study population.

Level	Transverse pedicle isthmus width (mm)	Pedicle length (mm)	Transverse pedicle angle (°)	Chord length (mm)	Canal dimensions (mm)	
					AP	IPD
T1	9.27 + 1.01	17.2 + 1.34	35.4 + 2.21	30.30 + 2.11	19.03 + 1.11	24.22 + 1.61
T2	7.5 + 1.13	18.6 + 1.43	26.21 + 4.12	32.30 + 3.24	22.21 + 1.09	23 + 1.22
T3	6 + 1.23	14.32 + 1.12	20.01 + 2.22	33.21 + 2.64	21.1 + 1.27	22.4 + 1.34
T4	4.5 + 0.93	14 + 1.34	19.06 + 3.12	36.5 + 2.26	20.02 + 1.23	21.38 + 1.11
T5	5 + 1.12	14.56 + 1.22	16 + 2.12	37.83 + 3.24	20.11 + 1.19	21.12 + 1.23
T6	5.5 + 0.742	14 + 1.32	14.38 + 2.24	39.84 + 3.58	20.09 + 1.17	23.18 + 1.52
T7	6 + 1.16	14.32 + 1.13	11.82 + 2.38	40.07 + 4.03	20.23 + 1.26	21.23 + 1.49
T8	6.32 + 1.56	14.56 + 1.08	12.29 + 2.11	40.64 + 3.29	18.03 + 1.19	21.31 + 1.65
T9	6.28 + 1.32	17.26 + 1.11	11.21 + 2.33	39.54 + 2.88	20 + 1.37	23.11 + 1.92
T10	6.54 + 1.12	14.54 + 1.39	8.7 + 2.38	40.11 + 3.45	17.03 + 1.27	20.09 + 2.18
T11	7.84 + 1.33	15.30 + 1.43	−2.3 + 7.34	36.21 + 4.08	19.13 + 1.60	23.12 + 1.14
T12	8.31 + 1.83	17.72 + 1.28	−9.8 + 2.39	34.24 + 3.33	20.14 + 1.19	24.24 + 2.23

found between right and left pedicle and transverse process data, and between age groups in all parameters measured. Therefore, the right and left pedicles were analyzed together.

Table 1 shows the tabulated data of the pedicle and vertebral canal dimensions.

3.2. *Transverse pedicle isthmus width (TPIW)*

Minimum pedicle width was observed at levels at T4 (4.5 ± 0.93 mm) and T5 (5 ± 1.12) level and maximum towards both the ends of thoracic spine [T1 (9.27 ± 1.01 mm) and T12 (8.31 ± 1.83)]. At T4 76% and at T5 62% of the pedicles were smaller than 5 mm and would not accept 4 mm screw with 1.0-mm clearance. However, at T1 2%, at T11 7% and at T12 8% would not accept a 4 mm screw.

3.3. *Pedicle length*

Pedicle length showed an increasing pattern from T1 to T2 followed by a rather constant pattern from T3 to T8.

3.4. *Transverse pedicle angle (TPA)*

TPA showed decreasing trend from T1 to T12 with last two vertebrae having outward angulation. Maximum medial angulation was seen at T1 (35.4 ± 2.21°) and a minimum T12 (−9.8 ± 2.39°).

3.5. *Chord length*

Chord length gradually increased in upper thoracic vertebrae and was relatively constant in middle and decreased in lower thoracic vertebrae. Shortest estimated chord length was at T1 (30.30 ± 2.11). On an average, from T1 to T6 and at T11 and T12, a screw length of 25–30 mm could be accommodated and from T7 to T10 30–35 mm, screw length could be accommodated.

3.6. *Canal dimensions*

The IPD gradually decreased from T1 to T5 to minimum value at T5 with mean of 21.12 ± 1.23 mm and then increased till T12 region with mean of 24.24 ± 2.23 mm. The APD had relatively stable values between T1 and T12. The minimum mean value was observed at T4 (20.02 ± 1.23 mm).

3.7. *Vertebral body height at anterior and posterior ends*

Both anterior (VBHa) and posterior (VBHp) vertebral body heights showed increasing trends from T1 to T12 and VBHp was higher at all levels compared to the VBHa (Table 2). The

Table 2 – Tabulated data of vertebral body, spinous and transverse process dimensions in the study population.

Level	Vertebral body height		Mid vertebral body width (mm)	Spinous process angle (°)	Transverse process length (mm)
	Anterior	Posterior			
T1	18.91 + 1.34	19.81 + 2.01	33.06 + 2.11	30.11 + 6.74	23.54 + 2.12
T2	18.98 + 1.41	20.12 + 1.13	32.01 + 3.12	30.29 + 5.34	26.25 + 2.34
T3	20.22 + 1.31	21.24 + 1.31	32.76 + 2.41	34.12 + 8.91	26.28 + 2.11
T4	20.98 + 1.38	22.34 + 1.23	34.23 + 2.33	40.24 + 8.11	28.43 + 1.85
T5	22.71 + 1.49	23.39 + 1.41	36.12 + 2.69	51.36 + 6.32	29.70 + 1.70
T6	22.88 + 1.51	23.31 + 1.31	37.48 + 2.71	57.89 + 9.31	30 + 1.83
T7	24.21 + 1.49	25.21 + 1.27	38.12 + 2.14	57.11 + 8.71	31.21 + 1.91
T8	24.81 + 1.21	25.66 + 1.31	38.21 + 2.71	52.23 + 8.64	30.91 + 2.11
T9	25.77 + 1.41	26.31 + 1.29	39.62 + 2.23	44.65 + 7.12	30.4 + 2.13
T10	27.72 + 1.33	29.12 + 1.31	43.10 + 2.71	40.12 + 7.08	26.12 + 2.90
T11	28.12 + 1.22	29.67 + 1.43	42.76 + 2.66	30.11 + 6.71	20.18 + 2.71
T12	28.91 + 1.34	30.41 + 1.38	44.21 + 3.21	16.21 + 7.38	12.11 + 2.3

minimum VBHa body was observed at T1 with the mean of 18.91 ± 1.34 mm. The height gradually increased to a maximum value at T12 level with the mean of 28.91 ± 1.34 mm. The VBHp had a minimum value at T1 region with the mean of 19.81 ± 2.01 mm. The height increased gradually and reached maximum at T12 region with the mean of 30.41 ± 1.38 mm).

3.8. *Mid vertebral body width (VBW)*

Mid vertebral body width showed increasing trend from T1 to T12. There was slight decrease in VBW from T1 (33.06 ± 2.11 mm) to T3 (32.76 ± 2.41 mm) (Table 2).

3.9. *Spinous process angle (SPA)*

The SPA increased from T1 (mean of 30.11 ± 6.74°) and reached maximum value at T6 level with the mean values of 57.89 ±9.31°. The angle then decreased gradually and reached minimum value at T12 level with the mean values of 16.21 ± 7.38° (Table 2).

3.10. *Transverse process length (TPL)*

The TPL increased from T1 (23.54 ± 2.12 mm) and reached maximum value at T7 with mean of 31.21 ± 1.91 mm. Then, the length decreased gradually to reach minimum value at T12 with the mean of 12.11 ± 2.3 mm (Table 2).

4. Discussion

With the increasing number of surgical and anaesthetic procedures being done in the thoracic vertebral column all over the world, a thorough knowledge of anatomical and radiological parameters is required.[5,24,32–35] Advent of new assistive devices like c-arm, CT scan and navigation has made these procedures a bit easy; still knowledge of pre-procedure normative data is required to decrease complication rate. The present study presents the detailed CT morphometric data of the thoracic spine.

4.1. *Transverse pedicle width*

Pedicle width is an important parameter for transpedicular procedures including pedicle screw (PS) placement. Minimal clinically relevant PS has 4.0 mm-diameter with 1.0 mm clearance.[33] Prior biomechanical analysis has shown that pedicle deformation and loss of purchase can occur when screw diameter is >80% of the outer cortical diameters.[34] Based on the analysis of the present study in the mid-thoracic region 76% pedicles at T4 and 62% at T5 would not accommodate a 4.0 mm PS compared to the junctional areas [T1 (2%), T11 (7%) and T12 (8%)]. Kretzer et al. suggested that if narrow pedicle width does not allow safe pedicle cannulation, salvage options include the use of laminar hooks or translaminar screws, PS placement into the combined pedicle-rib head width through an ''in-out'' approach or skipping the given spinal level followed by the placement of the instrumentation above and below the skipped pedicles.[33] We agree with other studies that pedicles between T4 and T8 should be measured on CT scans before surgery, because they might not be suitable for instrumentation with PS due to their narrow width.[8,29,30] We are of the opinion that other transpedicular procedures like biopsy, kyphoplasty and decompression should preferably be attempted with great caution in this region of the vertebral column to avoid injury to spinal cord and vital organs.

4.1.1. *Transverse pedicle angle (TPA)*

The TPA in the present study gradually decreased caudally. Anterolateral angulation was seen in the lower thoracic pedicle (T11, T12). In the studies conducted by Acharya et al.[30] and Chadha et al.,[27] they also reported anterolateral angulation at lower thoracic pedicles in Indian population, while studies by Datir and Mitra[26] and Pai et al.[8] pedicles showed decreasing trends in TPA but at no levels pedicles were facing laterally. Zindrick et al. reported TPA of lower thoracic vertebrae (T10, T11 and T12) approaching zero, and even negative in some cases.[25] We agree with Acharya et al. that this anterolateral angulation is important while placing PS, as space available for cord is less at thoracic level and any advertent medial perforation because wrong placement can put cord at risk and cause vascular injury.[30] Kretzer et al. reported a small but statistically significant difference in ideal right screw trajectory compared with from T3 to T12. On average, a 1.7° increased pedicle angle was required on the left side from T3 to T12. They attributed this finding to the medialisation of the aorta as it descents in the left paraspinal region of the thorax, causing small but significant changes in the development of the left side of the vertebral body and adjoining pedicle.[33]

4.1.2. *Pedicle length and chord length*

The pedicle length in the present study showed an increasing pattern from T1 to T2 followed by a rather constant pattern from T3 to T8. Similar trends were also reported in a cadaveric thoracic spine study from India.[1] The chord length increased gradually from T1 to T10 and decreased in lower two thoracic levels (T11 and T12) due to outward angulation present at these levels. This measurement is important in preventing anterior cortex perforation and therefore consequent injury to vital organs and major blood vessels. CT measurements in the present study are comparable to other studies from India,[26,27,30] but are smaller than those of western literature.[11,24,25,32,33] Based on the present study, safest screw length is 25–30 mm at T1 to T6 and T11 to T12 and 30–35 mm at T7 to T10. The transpedicular screw is about two times longer than translaminar or transcorporal screw at the same level. Besides that, additional advantages of transpedicular screw are that a pedicle mostly consisted of strong cortical bone in comparison to the cancellous vertebral body bone structure, and that such a screw passes through all three vertebral columns (posterior, middle, anterior).[32]

4.1.3. *Canal dimensions*

Canal dimensions are very important for both anaesthetists and surgeons, as cord canal ratio in thoracic spine is small, especially in the mid-thoracic region. The mid-thoracic region is important because it is the critical vascular zone for spinal cord. It has the narrowest opening, and the blood to the spinal cord is least perfused.[1] Surgical situation in this site is further compounded by the fact that this is the area of least pedicular width also. The epidural space at the posterior space in the adult measures about 7.5 mm in the upper thoracic region and 4.1 mm at T11–12 region. The space is far greater than that of the subarachnoid space at the same level. It takes about 1.5–2.0 ml of a local anaesthetic to block a spinal segment in the epidural space while the volume (0.3 ml) is far less in the subarachnoid space for a similar block.[5]

A segmental temporary sympathetic block during TEA is assumed to be an important mediator of the perioperative effects of TEA. In humans, a sympathetic block involving splanchnic and lower limb nerves occurred during a limited upper thoracic sensory block with high TEA after injection of 4.2 ml of 0.75% bupivacaine. Mid-thoracic TEA with 10 ml of 0.25% bupivacaine induced a thoracic sympathetic block that included the legs. In contrast, only segmental sympathetic block was found with a high thoracic TEA using 4 ml bupivacaine 0.5%. The concentration and volume of the local anaesthetic may determine the intensity and the limits of the sympathetic block. TEA has been shown to decrease adverse perioperative cardiac events. Better pain relief with concomitant reduction in the postoperative stress response and systemic sympathetic activity may contribute to this effect.[36]

Trends observed in the IPD were similar to the literature. However, two studies by Datir and Mitra[26] and Chaynes et al.[9] showed higher values at all levels and with uniformly increasing trends from T11 to T12. Biscevic et al. reported that IPD on second and third thoracic vertebra was shorter than on first thoracic vertebra.[32] The APD had relatively stable values between T1 and T12. The minimum mean value was observed at T4 (20.02 ± 1.23 mm), and findings similar to the present study were reported in the cadaveric study.[1]

4.1.4. *Vertebral body height*

Anterior and posterior VBHs difference accounts for normal physiological kyphosis present in the thoracic region. CT measurements of VBH were comparable to the previous cadaveric study from India[1] and also compared to Chinese Singaporean population reported by Tan et al.[17] VBHa was found to be less as compared to the VBHp at all levels. This observation is similar to the previous cadaveric study and explains for the normal physiological kyphosis present in the thoracic region.[1]

4.1.5. *Vertebral body width*

The VBW showed slight decrease from T1 to T3 and started increasing gradually till 12th thoracic vertebra. Similar trends were reported in other studies also.[1,32] This trend in the thoracic spine is related to vertical human posture and gradual increment of weight bearing from T11 to T12.[1,32]

4.1.6. *Transverse process length*

The TPL was relatively constant between T2 and T10 with the mean of 26.25 ± 2.34 mm at T2 to 26.12 ± 2.00 mm at T10. At T11 and T12, transverse process was smaller with mean value of 20.18 ± 2.71 mm and 12.11 ± 2.3 mm respectively. Similar trends were reported in the cadaveric study from India.[1]

4.1.7. *Spinous process angle*

In the present study, SPA increased from T1 (mean of $30.11 \pm 6.74^\circ$) and reached maximum value at T6 level with the mean values of $57.89 \pm 9.31^\circ$. The angle then decreased gradually and reached minimum value at T12 level with the mean values of $16.21 \pm 7.38^\circ$. This orientation of spinous process can be explained on the anatomical basis and it influences the movements of the spine.[1,4] The normative data of the SPA collected in the present study can be utilized to guide the needle introduction for thoracic anaesthetic procedure like epidural catheter placement for anaesthetic and pain relief purposes. A thoracic epidural block is relatively more difficult, especially mid-thoracic region (T5–8), than administering it in other regions, because the spinous process of the thoracic vertebra is longer than that of the lumbar vertebra, and the epidural space is relatively smaller due to an acute angle and larger distance between the skin and the epidural space. The laminae of adjacent thoracic vertebrae are also overlapping, making the interlaminar spaces in the thoracic spine extremely small and difficult to access. The thoracic transverse processes arise posterior to the articular processes and articulate with the corresponding rib. The presence of a rib is an identifying feature of the transition between L1 and T12 vertebra.[37]

Besides various benefits, TEA is associated with various complications, the most important being the risk of epidural bleeding resulting in epidural haematoma in the perioperative patient. Patient age and sex seem to be a major influence in vertebral column haematoma after TEA. The higher risk for older patients may be related to different causative factors such as reduced epidural space or degeneration of the spine, resulting in more frequent traumatic puncture. Iatrogenic pathogen inoculation and haematogenous infection of the insertion site or the epidural catheter are the potential causes also resulting in infection while administering thoracic epidural within the vertebral canal.[36]

Difficulties are also associated with needle insertion and placement of catheters (particularly in the high- and mid-thoracic epidural space) and persistent perioperative hypotension may be faced by anaesthetist.[6] Successful placement of the epidural needle depends greatly on anatomic changes in vertebrae. Another consideration to be made for a thoracic epidural block is the risk of serious neurological complications such as spinal cord injury, possibly resulting from the smaller epidural space in the thoracic region compared to that in the lumbar region. Thorough evaluation of anatomy can result in administration of block in much safe manner.[35]

Table 3 shows the summarized various studies from the literature on thoracic or lumbar pedicles to decide on the novelty of idea of the present study.

The present study has few limitations. First, a relatively low number of thoracic vertebrae were analyzed. The individual physiological and pathological variations of each parameter point on the necessity of analyzing more vertebrae and giving a wide overview of these variations. Another limitation of this study is that axial CT scan provides only a two-dimensional view of pedicles. Human pedicles form a complex three-dimensional shape rather than perfect cylinders, which is difficult to extrapolate from axial images. Another limitation is that 4 mm slice thickness used in the present study can miss valuable information between the slices. Few Indian studies, viz. Datir et al.,[26] and Shetty et al.,[38] used 5-mm cut section, while Acharya et al.[30], Chadha et al.[27] and Pai et al.[8] have used

Table 3 – Tabulated various studies from the literature studied on thoracic or lumbar pedicles to decide on the novelty of idea of the present study.

Study	Important observations and conclusions of the study
Zindrick et al., 1987[14]	Pedicle dimensions and angles change throughout the spine. A detailed knowledge of these relationships is important for any surgeon contemplating the use of the pedicle for screws purchase to prevent screw cutout and failure of fixation or neurologic injury.
Kim et al., 1994[21]	The results suggest that using 6-mm screws can violate the cortex of the pedicles in a significant number of levels of the upper lumbar spine. Using a screw longer than 40 mm is dangerous in the lower thoracic spine of a Korean.
Vaccaro et al., 1995[24]	The precise morphology of the individual patient's vertebrae must be determined with the use of pre-operative computerized tomographic scans to define three important variables: the angle of insertion of the pedicle into the vertebral body, the transverse diameter of the pedicle, and the cord length.
Ebraheim et al., 1997[11]	This information, in conjunction with preoperative computed tomography evaluation, may enhance our knowledge of transpedicular screw fixation in the thoracic pedicle.
Cinotti et al., 1999[10]	Pedicles between T4 and T8 may not be wide enough for screw fixation.
Ugur et al., 2001[13]	The following suggestions are made based on the results. (1) More care should be taken when a transpedicular screw is placed in horizontal plane. (2) Improper medial placement of the pedicle screw, especially in the middle thoracic spine, should be avoided, and the anatomic variations between individuals should be considered. (3) Because of substantial variations in the size of thoracic pedicles, utmost attention should be given to the findings of a computed tomographic evaluation before thoracic transpedicular fixation is begun.
McLain et al., 2002[23]	Even the largest patient had some pedicles that could not accommodate the smallest standard pedicle screws, and more than half of the pedicles average patients were too small.
Chadha et al., 2003[27]	It is suggested that preoperative computed tomography scans of the patients must be evaluated to choose the appropriately sized implant and avoid inadvertent complications. Preparation of the pedicle intraoperatively should take into account the orientation of the transverse pedicle angle.
Datir and Mitra 2004[26]	The results suggest that even a 4-mm screw should be used carefully at the midthoracic level; 5-mm screw seems to be safe at upper and lower thoracic spine. Because of very small sagittal and transverse angles at mid and lower thoracic levels, the pedicular screws should be inserted along perpendicular line in these planes; 25-mm and 30-mm screw length appears to be safe at upper thoracic and lower thoracic levels, respectively.
Tan et al., 2004[17]	Compared to the Caucasian data, all the dimensions were found to be smaller. Of significance were the spinal canal area, and pedicle width and length, which were smaller by 31.7%, 25.7% and 22.1% on average, respectively.
Christodoulou et al., 2005[28]	Pedicle dimensions at the levels from T3 to T8 need preoperative evaluation with computed tomography before the insertion of pedicle screws with diameter more than 5 mm. Pedicles at T12 to L5 levels may accommodate screws of 7 mm diameter.
Liau et al., 2006[29]	The safe level for transpedicular fixation using 4.5-mm screw appears to be at T1, T2, T11, and T12. However, even at these levels, up to 20% of female patients and up to 6.7% of male patients have pedicle diameter of less than 5.5 mm. Safe screw length was between 30 mm and 35 mm. A 40-mm screw would be too long for thoracic spines in this population.
Pai et al., 2010[8]	Knowledge of the pedicle diameter and chord length is essential for choosing the appropriate pedicle screw, whereas the pedicle angle and the entry point are important for accurate screw placement.
Acharya et al., 2010[30]	Significant differences exist between the pedicles of Indian and white populations. It is suggested that preoperative software-based morphometric data should be collected if possible for preoperative planning of pedicle implant placement and sizes to avoid inadvertent complications.
Singh et al., 2011[1]	The smallest diameter screw and shortest available screw for adults are not safe in majority of the Indian population in mid-thoracic region. The results of the present study can help in designing implants and instrumentations; understanding spine pathologies; and management of spinal disorder in this part of the world.
Shetty et al., 2011[38]	These results show that 5 mm screw should be safe at upper and lower thoracic spine; 26–28 mm screw length appears to be safe at upper and lower thoracic level. Even 4 mm diameter screw was used with care in mid thoracic region. Because of the smaller pedicle size and more proximity to the spinal cord and the neurovascular structure, the pedicle screw fixation is difficult. Hence, precise knowledge of the pedicular dimension and pedicular entrance point is essential for thoracic pedicular screw fixation.
Kretzer et al., 2011[33]	Preoperative CT evaluation is important in choosing PS length, diameter, trajectory, and entry point due to variation based on spinal level, patient sex, and side of placement. These data are valuable for resident and fellow training to guide the safe use of thoracic PSs.
Biscevic et al., 2012[30]	For accurate performing of transpedicular screws, knowledge of anatomical and radiological characteristics of spine is essential.
Avuthu et al., 2014[39]	Pre-operative computed scan is recommended to choose an appropriately sized implant and avoid complications.

3-mm cut sections. However, after comparing the data of the present study, we have found no significant difference between these studies. It is very important using the bone window the cut section of CT where the right and left pedicles appear largest are selected for the pedicle, canal and transverse process dimensions measurements.

5. Conclusions

A thorough knowledge of anatomical and radiological characteristics of the spine and their variations is essential for the clinicians. Data collected in the present study provides baseline normative values in Indian population and will help in guiding safe and effective completion of both surgical and anaesthetic procedures in the thoracic spine. Computer software aided morphometric data can help in selecting appropriate size and optimal placement of the implant with minimal procedural difficulties and complications during spine surgery.

Conflicts of interest

The authors have none to declare.

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