Original Article

Measurement of thoracic and lumbar pedicle dimensions in Nigerians using computed tomography

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Abstract

Background: Pedicle screws are often used to stabilise the spine. They afford the benefit of a three-column control of the spine. The technique of pedicle screw insertion is familiar and has a well-documented safety profile during lumbar and thoracic spinal surgery. However, complications such as cerebrospinal fluid leakage due to pedicle screw misplacement, neurological irritation and pedicle penetration may occur. Therefore, knowledge of the dimensions of spinal pedicles is necessary for the fixation of pedicular screws to avoid possible complications.

Aims: The aim of this study was to determine the maximal diameter and axial length of thoracic and lumbar pedicles in a homogenous African population using computed tomography (CT). This would establish normative data on the average size of pedicle screws that would be required during the surgery, hence maximising pull-out strength while reducing the possibility of revision of the pedicle screw placement.

Methods: It is a retrospective study where the transverse pedicle width, axial pedicle length and sagittal pedicle width of T1–L5 were measured on 100 patients; 50 males, 50 females with normal spinal architecture using a 128-slice Toshiba CT scanner.

Results: The mean axial length in the thoracic and lumbar vertebrae ranged from 31.76 ± 2.92 mm (T1) to 43.02 ± 3.32 mm (T12) and from 45.07 ± 2.40 mm (L5) to 46.32 ± 2.28 mm (L3), respectively. The mean TPW at the thoracic and lumbar vertebrae ranged from 4.53 ± 0.69 (T4) to 7.78 ± 1.31 mm (T12) and from 6.81 ± 1.25 mm (L1) to 12.95 ± 1.49 mm (L5), respectively. The mean sagittal diameter of thoracic and lumbar vertebrae ranged from 5.78 ± 1.07 mm (T1) to 10.98 ± 1.37 (T12) and from 9.51 ± 1.31 mm (L2) to 9.78 ± 1.61 (L4), respectively.

Conclusion: The dimensions of thoracic and lumbar pedicles measured in this study vary with those obtained from other populations. This strengthens the case for customising the existing range of spinal pedicle screws according to local population characteristics.

Keywords: Computed tomography, lumbar spine, pedicle screw, thoracic spine

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Received: 21.08.2019, **Accepted:** 23.12.2019, **Published:** 30.04.2020

INTRODUCTION

Pedicle screws are devices designed for implantation in the vertebral pedicles during spinal surgery. Used along with rods, they are versatile tools in a wide range of spinal surgeries, including deformity correction, spinal fusion and stabilisation. Today's pedicle screw is a magnetic resonance

Access this article online

Quick Response Code:

Website: www.phmj.org

DOI: 10.4103/phmj.phmj_17_19

How to cite this article: Badmus O, Ogbe P, Olowoyeye OA, Akinsulire A, Omidiji O. Measurement of thoracic and lumbar pedicle dimensions in Nigerians using computed tomography. Port Harcourt Med J 2020;14:12-8.

imaging compatible polyaxial screw made of titanium which is highly resistant to weakness and corrosion. The pedicle screw length ranges from 30 mm to 60 mm (up to 2½ inches) and the pedicle screw diameter ranges from 5.0 mm to 8.5 mm (up to ¼ inch). The screws hold bony structures together, thus serving as an anchor in the immobilisation of part of the spine. Pedicle screws may be used in instrumentation procedures to fasten rods and plates to the spine just like other bone screws. To determine the depth and angle for screw placement, the surgeon uses conventional radiography or intra-operative fluoroscopy.[1]

Spinal instrumentation constructs utilising pedicle screws as segmental anchors within the thoracolumbar spine have become widely accepted in the treatment of a wide range of spine problems, including deformities, trauma, degenerative disorders, infections and neoplastic disorders. They afford advantages of three-column control of the spine, the familiarity of the approach and landmarks for insertion, as well as a well-documented safety of their insertion and use in both the lumbar and thoracic spine. One method of failure of these constructs is termed pullout.[2] The pull-out strength is the force that would have to be applied to pull, i.e., tear, a screw out of its anchoring in bone. Chapman *et al*.[3] concluded that the pull-out strength of a pedicle screw is determined by several factors such as the outer diameter and fit of the pedicle screw in the bony canal created within the pedicle, as well as the length of the screw in the vertebral body. Thus, while knowledge of the spinal pedicle anatomy and their relationship with neural structures is necessary to optimise fixation of pedicle screws, it is equally important to know the size and dimensions of screws for each vertebral level to minimise complications.

Pedicle screws are safe when properly placed and are versatile devices used for a wide range of procedures from fracture fixation to complex deformity correction.[3] They have been safely used in patients from all age groups, including the paediatric population as young as 1 year.[4] Pedicle screws have been shown to be safer than other constructs and are also biomechanically superior when compared to the previously used rod and hook systems.[5,6]

Originally, pedicle screws were readily used in the lumbar spine, where pedicles are thicker and hence easier to cannulate and generally had paths that did not adjoin essential neural or vascular structures. However, the characteristic biomechanical advantages of pedicle screws led to their utilisation in the thoracic spine.[7] In the thoracic vertebrae, there is undeniably a much lower margin of error, as screws not properly placed or too large are capable of injuring the spinal cord and other structures closely associated with the vertebrae, including the thoracic pleura, oesophagus and intercostal and segmental vessels. Other structures within the thoracic cavity at risk include the aorta, inferior vena cava, thoracic duct and azygous vein.[8] Apart from complications associated with normal anatomy, pedicles can be difficult to cannulate due to presenting pathologies.

The pedicle is subject to ethnic variations, as reported in various studies. There is, therefore, the need for ethnic-specific data on pedicle dimensions to minimise misplacement and insertion of inappropriately sized implants with attendant injury to patients despite the best efforts of spine surgeons.[9,10]

The success of the technique depends on the ability of the screw to be stable within the vertebral body. This is influenced, among other factors, by the size of the pedicle, the accuracy of choice of screw and the quality of the bone of the pedicle.

Use of relatively oversized screws may result in penetration of the cortex or fracture of the pedicle and some of the complications that have been reported include dural tears, leakage of cerebrospinal fluid and injuries to the nerve roots with neurological deficits.[5,11,12] The minimum diameter of the pedicle determines the choice of the pedicle screw to be used because larger sizes will cut through the pedicle and may cause injury. Morphometric data on the diameters of the pedicles are thus beneficial in pre-operative planning and in the designing of pedicle screws.[13]

Hence, this study is essential to establish the normative pedicle morphometric data for a Nigerian population and to determine the common sizes of pedicle screws to be used on Nigerians and stratify these data by gender.

To the best of our knowledge, there has not been any study that defines thoracolumbar pedicle dimensions in a local population in Nigeria.

METHODS

The study was carried out from February 2018 to July 2018 at the Lagos University Teaching Hospital, Lagos, Nigeria. All information obtained was treated with the utmost confidentiality. The study included both male and female patients of Nigerian origin who were 18 years of age or older that had computed tomography (CT) of either the thoracic or lumbar spine as part of the evaluation for nonspinal pathologies. Patients with a history of spinal surgery, obvious deformities of the spine and/or any old or recent spinal fracture were excluded from the study. Ethical clearance was obtained from the Institutions Human Research Ethics Committee according to the Helsinki declaration of 1975 for this retrospective study that required access to patient-identifiable data without patient consent.

Thoracic and lumbar spine CT scans from 100 patients were evaluated in this study by a radiographer who was appropriately trained in taking measurements. Other researchers included two radiologists and two spine surgeons who gave the required input and guidance. Fifty patients for thoracic (25 men and 25 women) and 50 patients for lumbar (25 men and 25 women) were assessed. All of the patients, who were 18 years of age or older, were requested to undergo CT scans for complaints unrelated to the vertebral spine and no evidence of spinal pathology was seen on their CT scan. Patients who had a history of spinal surgery, obvious deformities of the spine and/or any old or recent spinal fracture were excluded.

CT images were obtained using a Toshiba 128-slice CT scanner. Only bone-window axial and sagittal images were evaluated in this study. The transverse pedicle width, axial length and sagittal pedicle width of T1–T12 and L1–L5 were measured on CT images of the patients. All parameters were measured by one of the investigators and were measured twice to ensure consistency. These variables were measured to determine the maximal diameter and length of the pedicle screws to be used in the study population. The transverse pedicle width is the width of the narrowest point of the pedicle in a line perpendicular to the pedicle axis [Figures 1a and 2a].

The axial length is the point between the anterior border of the vertebral body and the entry of the pedicle screw [Figures 1a and 2a]. The sagittal diameter or pedicle height was measured as the superior-inferior distance of the pedicle in the sagittal plane [Figures 1b and 2b]. All pedicle measurements were bilaterally performed from T-1 to L-5 and were stratified by patient gender and the side of placement.

All data were entered, checked and analysed using the (Statistical Package for the Social Sciences version 25.0. IBM Corp. Armonk, NY) Independent Student's *t*-test was used for comparison between the means of two groups. The $P < 0.05$ was considered statistically significant.

RESULTS

No significant difference was found between the right and left pedicles in all parameters measured. Thus, the right and left pedicles were analysed together in this study. All data are presented in charts and tables. The mean age of participants was 45.90 ± 13.56 years. The age range for patients who provided data on the lumbar vertebrae was 49.04 ± 13.73 for males and 47.00 ± 7.95 for females. While the age range for patients who provided data on the thoracic vertebrae was 48.04 ± 14.19 for males and 43.92 ± 12.91 for females.

The thoracic vertebrae

The mean axial length of the thoracic vertebrae ranged from 31.76 ± 2.92 mm at T1 to 43.02 ± 3.32 mm at T12 [Figure 3]. There was progressive increase in the axial lengths of vertebrae from T1 to T12. The mean transverse pedicle width of the thoracic vertebrae ranged from 4.53 ± 0.69 at T4 to 7.78 ± 1.31 mm at T12. The mean sagittal diameter of the thoracic vertebrae ranged from 5.78 ± 1.07 mm at T1 to 10.98 ± 1.37 mm at T12. There was a progressive increase in sagittal diameter from T1 to T12.

There was a statistically significant difference in the mean axial lengths of T1–T12 vertebrae ($P < 0.001$) between

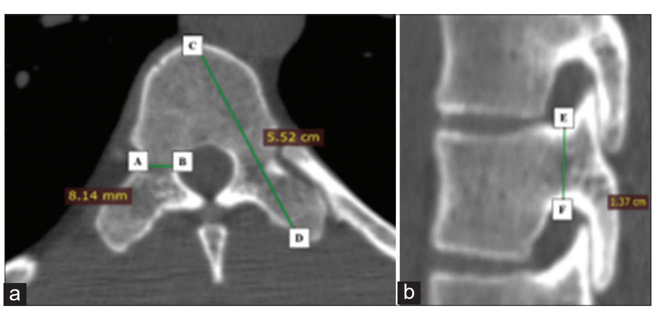

Figure 1: Computed tomography scan images of the thoracic spine obtained using a Toshiba 128-slice computed tomography scanner. (a) Axial view of the T9. The line between A and B represents the transverse diameter (pedicle width), while the diagonal line between C and D is the longitudinal pedicle axis of T9. (b) Sagittal view of the T9. The line between E and F illustrates sagittal diameter (pedicle height) of T9

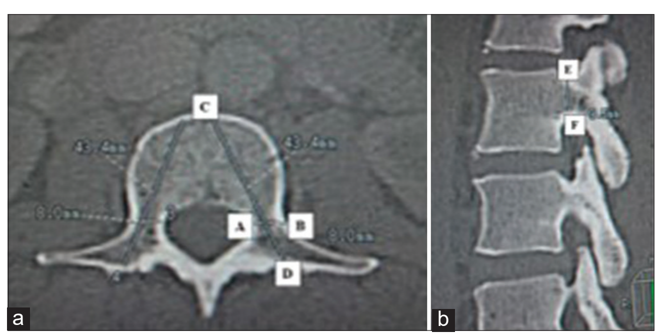

Figure 2: Computed tomography scan images of the lumbar spine obtained using a Toshiba 128-slice computed tomography scanner. (a) Axial view of the L2. The line between A and B represents the transverse diameter (pedicle width), while the diagonal line between C and D is the longitudinal pedicle axis of L2. (b) Sagittal view of the L2. The line between E and F illustrates sagittal diameter (pedicle height) of L2

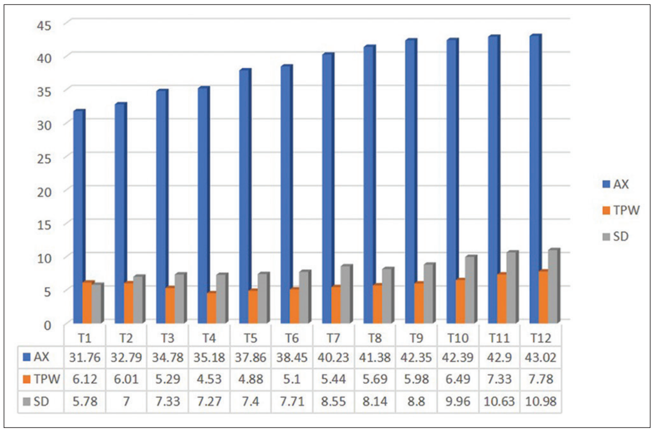

Figure 3: Bar chart showing the mean dimensions for the axial length, transverse pedicle width and sagittal diameter of the thoracic vertebrae

male and female patients. The axial length was progressively longer in males from T1 to T12 than females [Table 1]. There was a statistically significant difference in the sagittal diameters of T2 ($P < 0.001$), T4 ($P = 0.016$), T6–T9 ($P < 0.05$), between male and female participants. There was a significant difference in the transverse pedicle widths of T2–T9 ($P < 0.05$) and T12 ($P < 0.001$) between male and female patients [Table 2].

The lumbar vertebrae

The mean axial length of the lumbar vertebrae ranged from 45.33 ± 2.13 mm to 46.32 ± 2.28 mm [Figure 4]. The third lumbar vertebra (L3) had the longest mean axial length (46.32 ± 2.28 mm). The mean transverse pedicle width of the lumbar vertebrae ranged from 6.81 ± 1.25 mm at L1 to 12.95 ± 1.49 mm at L5. The mean sagittal diameter of the lumbar vertebrae ranged from ranged from 9.51 ± 1.31 mm at L2 to 9.78 ± 1.61 mm at L4.

Between male and female patients [Table 3], there was a statistically significant difference in the mean pedicle axial lengths of L1–L3 vertebrae ($P < 0.05$). There was also a significant difference in the mean transverse pedicle width of L1 ($P = 0.014$), and L4 ($P = 0.030$). There was a statistically significant difference in the sagittal diameter of the first to fifth lumbar vertebrae (L1–L5) ($P < 0.05$).

DISCUSSION

The acceptance of pedicle screw technique was driven by increased surgeon ease and also the biomechanical advantage of pedicle screws over other methods of spinal fixation.[14-16] However, variations in anatomy can make screw placement challenging, and retrospective studies have revealed that even in experienced hands, pedicle wall violations can take place in up to 29% of cases.[17] The key to an effective trans-pedicular procedure is that the pedicle be safely penetrated; else serious complications, such as nerve, vascular, and visceral injuries, may occur. A penetration should preferably be placed along the axis of the pedicle, integrating the largest available transverse and sagittal pedicle diameters.[18] A precise understanding of the thoracic and lumbar pedicles and their relations with neural structures has essential implications for surgical interventions. Most surgeons use anatomic landmarks, often in conjunction with fluoroscopy, to guide pedicle screw placement in the spine.[19] Neuronavigation has been shown to improve the accuracy of screw placement, but it adds to the resources and time needed for surgery.[19-21]

Table 1: Comparison of axial length of thoracic vertebrae between male and female patients

Variable (mm)	Mean±standard deviation		*t*	*P*
	Male (*n*=25)	Female (*n*=25)		
AXT1	33.77±2.42	29.75±1.78	6.69	<0.001
AXT2	34.35±1.11	31.24±1.57	8.10	<0.001
AXT3	37.06±1.99	32.50±2.35	7.40	<0.001
AXT4	37.83±1.88	32.53±2.01	9.60	<0.001
AXT5	39.94±1.93	35.77±3.13	5.66	<0.001
AXT6	40.85±0.86	36.05±2.81	8.16	<0.001
AXT7	43.10±1.35	37.35±2.96	8.83	<0.001
AXT8	43.76±1.72	38.99±2.44	7.99	<0.001
AXT9	45.05±1.80	39.64±2.05	9.90	<0.001
AXT10	44.51±1.45	39.68±1.82	10.39	<0.001
AXT11	44.98±2.02	38.83±2.82	8.85	<0.001
AXT12	45.62±2.04	40.41±2.05	9.00	<0.001

AX: Axial length

Table 2: Comparison of thoracic vertebrae dimensions in male and female patients

Variable (mm)	Mean±standard deviation		*t*	*P*
	Male (*n*=25)	Female (*n*=25)		
TPWT1	6.14±0.67	6.09±0.97	0.20	0.839
TPWT2	6.45±1.0	5.58±0.95	3.15	0.003
TPWT3	5.73±0.89	4.85±0.92	3.41	0.001
TPWT4	4.74±0.26	4.31±0.90	2.30	0.029
TPWT5	5.08±0.28	4.68±0.69	2.70	0.011
TPWT6	5.38±0.63	4.81±0.58	3.34	0.002
TPWT7	5.89±0.39	5.00±0.82	4.92	<0.001
TPWT8	6.06±0.75	5.32±0.62	3.83	<0.001
TPWT9	6.53±0.67	5.43±0.62	6.04	<0.001
TPWT10	6.66±0.54	6.33±0.91	1.59	0.118
TPWT11	7.60±1.25	7.06±1.27	1.52	0.136
TPWT12	8.57±1.36	6.99±0.59	5.32	<0.001
SDT1	5.95±0.92	5.62±1.21	1.11	0.273
SDT2	7.85±0.69	6.60±0.98	7.04	<0.001
SDT3	7.58±0.80	7.07±1.41	1.58	0.122
SDT4	7.57±0.64	6.96±1.04	2.49	0.016
SDT5	7.62±0.84	7.17±1.47	1.32	0.195
SDT6	8.70±1.11	6.72±1.37	5.64	<0.001
SDT7	9.67±1.38	7.43±1.01	6.55	<0.001
SDT8	8.59±1.07	7.69±1.28	2.71	0.009
SDT9	9.24±1.40	8.36±1.34	2.27	0.028
SDT10	10.30±1.66	9.63±1.32	1.58	0.120
SDT11	10.94±1.90	10.32±1.75	1.43	0.160
SDT12	11.33±1.45	10.63±1.23	1.83	0.073

TPW: Transverse pedicle width, SD: Sagittal diameter

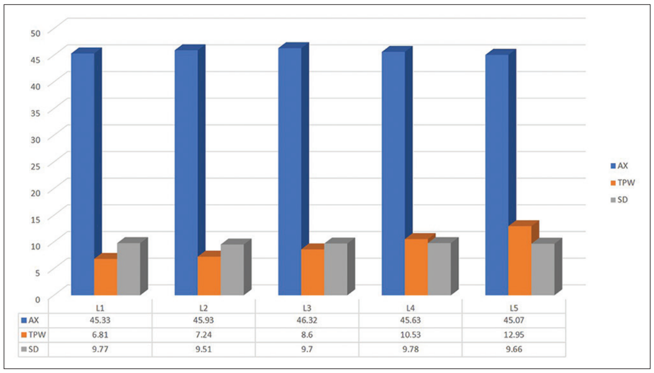

Figure 4: Bar chart showing the mean dimensions for the axial length, transverse pedicle width and sagittal diameter of the lumbar vertebrae

Table 3: Comparison of the lumbar vertebral dimensions between male and female patients

	Mean±standard deviation		t	P
	Male (n=25)	Female (n=25)		
AXL1	46.38±2.21	44.29±1.44	3.96	<0.001
AXL2	47.33±2.31	44.53±2.25	4.35	<0.001
AXL3	46.97±2.44	45.66±1.92	2.11	0.040
AXL4	46.24±2.13	45.03±2.14	2.00	0.051
AXL5	45.67±2.02	44.48±2.64	1.78	0.081
TPWL1	7.23±1.50	6.38±0.74	2.54	0.014
TPWL2	7.40±1.21	7.08±0.98	1.02	0.313
TPWL3	8.88±1.57	8.32±1.31	1.37	0.178
TPWL4	10.95±1.51	10.10±1.16	2.24	0.030
TPWL5	13.11±1.74	12.78±1.21	0.78	0.441
SDL1	10.40±0.88	9.14±1.30	4.01	<0.001
SDL2	10.08±1.22	8.94±1.16	3.39	0.001
SDL3	10.05±1.25	9.34±1.13	2.10	0.041
SDL4	10.45±1.45	9.11±1.50	3.22	0.002
SDL5	10.51±1.69	8.82±1.76	3.45	0.001

AX: Axial length, TPW: Transverse pedicle width, SD: Sagittal diameter

Many authors have described the details of the pedicle sizes and dimensions of the thoracic and lumbar spines by means of various techniques such as direct cadaveric measurement, plain X-ray radiographs and CT scan. Most of the studies concentrated on either the lumbar region[2,11,13,19] or the thoracic spine.[22,23] The dimensions of pedicles of the entire thoracolumbar vertebrae have been reported by only a few authors.[24]

This study presents morphometric data on thoracic and lumbar pedicles of the spine (T1–L5) in a homogenous African population by computer-aided CT-based measurements to clarify the anatomical parameters affecting the thoracic and lumbar choice of pedicle screw size for surgery. Furthermore, data were stratified based on patient gender and the side of screw placement to additionally define factors affecting the thoracic and lumbar choice of the pedicle screw. The parameters that were measured included the axial length, transverse pedicle width and the sagittal diameter.

The axial length which is the pedicle screw length was measured from the point between the anterior border of the vertebral body and the entry of the pedicle screw. This parameter was measured to determine optimal pedicle screw length. We found a progressive increase in the axial length from T1–T12 [Figure 3]. However, the increase in axial length was more prominent from T-1 to T-8 and then stabilised from T-8 to T-12. This general trend was similar to the measurements described by Kretzer *et al.*[22] and Zindrick *et al.*[11] The shortest measured axial length was 28 mm from T-1 to T-6 and 36 mm from T-6 to T-12 [Table 1]. Based on these facts, the placement of a minimum 25-mm pedicle screw is likely to be safe to the level of T-6, whereas below T-6 a minimum pedicle screw length of 35 mm is likely to be safe. When axial length was stratified by patient gender, thoracic spine pedicles in men were found to accommodate, on an average, a 4.0-mm longer screw length at every level compared with their counterparts in women [Table 1]. This outcome is similar to results reported by Lien *et al.*[23] in a study of thoracic spinal anatomy in the Malaysian population and highlights the utility of pre-operative CT evaluation before thoracic pedicle screw placement to avoid lung, mediastinal or vascular injury induced by the surgeon.[25,26]

The mean axial lengths of the lumbar vertebrae were closely related with the shortest mean being 45.07 ± 2.40 mm at L5 and the longest mean being 46.32 ± 2.28 at L3 [Figure 4]. There was a progressive increase in length from L1–L3, then a slight decrease from L3-L5. It was observed that the average axial length was around 45 mm for all lumbar levels. When axial length was stratified by patient sex [Table 3], lumbar spine pedicles in males were found to accommodate, on average, a 2.0-mm longer screw length at every level with their counterparts in females. It is not necessary to make screws of different lengths for this study group. For reasons of safety, the pedicle screw length should be <45 mm in female and male patients.

The transverse pedicle width was of the narrowest point of the pedicle in a line perpendicular to the pedicle axis. The oval-shaped pedicle screw is narrowest at the transverse plane. It is in this plane that the maximum allowable pedicle screw is ascertained.[11] In this study, the pedicle width decreased from T1–T4 gradually increased from T5–T12 [Figure 3]. When thoracic pedicle width was stratified by patient sex [Table 2], a striking difference was noted between male and female patients. Our findings that the pedicles in men were wider at every level than their counterparts in women should be considered when choosing appropriate screws for the thoracic vertebrae. In our study population, a minimum of 4.0-mm pedicle screws should be used at T4–T6, a minimum of 5.0 mm screw at T1–T3, T7-10 levels, and a minimum of 6.0 mm screw at T11 and T12 levels.

The average transverse pedicle width diameter in lumbar vertebrae ranged from 6.81 ± 1.25 mm at L1 to 12.95 ± 1.49 mm at L5 with a progressive increase in size from L1 to L5 [Figure 4]. Therefore, pedicle screws of 7.0 mm or higher can be used in the lumbar vertebrae except in L1 where <7.0 mm screw should be used. The data obtained from the measurement of the transverse pedicle diameter in our study were similar to that of Mistri[26] in 2016.

The sagittal diameter of the pedicles was generally wider than the transverse pedicle width except in T1, L4 and L5 vertebrae [Tables 2 and 3]. This shows that both diameters should be considered when determining the size of a suitable screw.

Several reports compare the dimension of pedicle between males and females. Olsewski *et al*.,[27] Christodoulou *et al*.,[21] and Kretzer *et al*.[22] found differences between men and women just like this study, but Urrutia *et al*.[2] did not find significant statistical differences in pedicle dimensions between male and female.

The dimensions obtained in this study were similar to some studies in the thoracic axial length[23] and thoracic and lumbar TPW.[8,23,27] However, the transverse pedicle width of the thoracic vertebrae were wider than the study of Lien *et al*.[24] but the TPW of the lumbar spine and sagittal diameter of T1–T12 were narrower than that of Lien *et al*.[24] and studies carried out in the Mexican and Egyptian populations.[2,19]

A limitation of the study is that the starting point of each pedicle from the vertebral bodies was not included in the measurements obtained. Neither was the pedicle axis (cranio-caudal and mediolateral angulation). Increasing the sample size in future studies may further minimise sampling errors.

CONCLUSION

Pre-operative CT evaluation may provide vital information when planning thoracic and lumbar pedicle screw fixation given the variation among individual patients as relates to patients' gender and spinal levels to avoid complications during and after the surgery. It was established that the dimensions found in this study differ from the results of other studies, hence strengthening the case for customising the existing range of spinal pedicle screws according to local population characteristics. Complications of pedicle screw fixation can be minimised if the ideal axial length and pedicle width is combined with established guidelines for choosing the optimal screw entry point and pathway.

Acknowledgement

The authors would like to thank Lagos University Teaching Hospital, Lagos, Nigeria.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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