Pattern of Pedicle Morphometry of Lumbar Vertebrae among Adult Ugandans Using Computed Tomography Scan Imaging

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Abstract-
Background
The number of patients with degenerative diseases and other causes of the lumbar spine diseases is increasing. Some of these patients are being managed operatively by spine instrumentation using pedicle screw systems. Pedicle morphometric studies are relevant for proper placement of transpedicular screws to avoid penetration of the pedicle walls. This study aimed at determining the morphometry of pedicles in the lumbar spine among adult Ugandans attending Mulago National Referral Hospital assessed using Computerized Tomography (CT) scans.
Methods
Across-sectional descriptive study was used in which measurements were taken from reformatted CT scan images and the minimum endosteal diameters at the isthmus of the pedicles. Comparison between both sexes, left and right pedicles was made. Data was expressed as mean ± standard deviation. Student t- test was employed for all statistical comparisons where p values < 0.05 were considered statistically significant in all analyses.
Results
Pedicles showed a gradual increase in the horizontal diameter in both sexes as the investigator moved from lumbar 1 to lumbar 5 (L1 to L5) with the largest horizontal diameter seen at L5. The vertical diameters also increased but to a lesser extent compared to horizontal diameter with maximum values being at l3 and then a steady decline seen up to L5. Pedicle axial angles increased from L1 to L5 but the sagittal angles decreased as the investigator moved from L1 to L5. There was no difference observed between the left and right pedicles.
Conclusion
In this study we found out that the subjects who attended Mulago National referral hospital with Lumbar Spine diseases, their pedicle morphometrical measures had slightly smaller measures compared to other populations. The female had smaller pedicle dimensions compared to their male counterparts and there were no overall differences between left and right pedicles in both sexes.

INTRODUCTION
The number of patients with degenerative diseases of the lumbar spine is increasing, which seems to be a natural consequence of aging due to the increase in life expectancy hence more exposure to vertebral insults by the time of one's death. It is estimated that between 70-90% of the general population suffer from low back pain with approximately 4% requiring surgery at some point in time [1]. Also, a variety of spine disorders such as fractures, spondylolisthesis and scoliosis are increasingly becoming common because of the lifestyle we lead. One treatment option for these disorders is lumbar fusion surgery which can be performed with open or minimally invasive techniques [2, 3]. Currently in the advanced world, minimally invasive surgery is preferred to the former because it offers advantages in postoperative recovery [4]. In order to perform a lumbar fusion using pedicle screws, it is necessary to have precise anatomical knowledge of lumbar pedicles. Several studies have been done to study the lumbar pedicle morphometry. Until now, there were reports regarding the morphology of pedicles in Americans, Indian, Koreans, Greek, Malaysian, and Japanese populations [5] [6], from the above studies, lumbar pedicle sizes have been shown to differ between ethnic races. Knowledge of pedicle dimensions and surface landmarks is crucial for the safe placement of pedicle screws, but no quantitative data concerning the lumbar pedicle using CT scans in a

Ugandan indigenous population existed. The aim of this study was to determine lumbar pedicle dimensions in a Ugandan population using computed tomography.

Methods

Study design and population

We performed a descriptive cross – sectional for over 8 months. Our aim was to determine the lumbar pedicle morphometry among adult Ugandans (above 18years). The study was carried out at Mulago National Referral Hospital. Mulago hospital is a national referral and teaching hospital for Makerere University with a bed capacity of about 1500. It is located 6 Km from Kampala city square in the capital city of Uganda with a population of about three million. The study population comprised of ninety-nine lumbar spine CT scan images of patients who presented to Mulago hospital radiology department during the time of this study. A total of 990 pedicles were assessed because in the lumbar region we have 5 vertebrae and each has 2 pedicles (left and right pedicles from L1 to L5). All CT scans of males and females 18 years and above which demonstrated all the lumbar vertebrae from L1 to L5 were included in the study. We invited 120 subjects and of these we excluded patients 21 with gross spine pathology, distorted pedicle and vertebral body anatomy. These included; Congenital anomalies like dysraphism, vertebra agenesis and other spinal dysplasias, Infections like tuberculous spondylitis, Tumors which destroyed the vertebra body and pedicles, and those who had ever undergone spine surgery like posterior fusion and corpectomy.

Sample size determination

Sample size determination was guided by applying Krejci and Morgans table formula and Sampling methods and [24]. Basing on them a confidence interval of 95% was set with a standard deviation of 2.9 and acceptable error of mean of 0.7mm we set a maximum sample size to 99 subjects

Data collection

There was consecutive enrolment of scan images of the Lumbar spine. All scans with morphologically abnormal vertebrae were excluded from the study. We collected 99 complete CT scan images of Ugandan patients of showing all the five lumbar vertebrae and giving a total of 990 pedicles.

The computerized tomographic scans were all made with a Philips CT scan machine (Philips MX 16 slice with an MX 16 slice gantry manufactured by Philips and Neurosoft Medical Systems Co. Ltd. China Class 1 Type B whose mode of operation is a Continuous operation with intermittent Loading). The whole lumbar spine segment was scanned continuously by an axial and helical scan mode with a slice thickness of 2mm.

To get sagittal scans, multi planar reformatting of the transverse images was done with the cuts along the optimal pedicle axis to get the isthmus sagittal section.

The following measurements were performed on both sides and then recorded in millimeters:

The transverse/ horizontal diameter of the pedicle at the level of the isthmus (minimum endosteal diameter and was measured at two points in the narrowest area of the endosteum of the isthmus in the axial plane. Further the sagittal /vertical diameter of the pedicle at the level of the isthmus (minimum endosteal and was measured at two points in the narrowest area of the endosteum of the isthmus in the sagittal plane.

Coaxial depth from the lamina to the anterior vertebral cortex (distance from the pedicle entry point shy of the facet joint capsule to the anterior vertebral cortex - chord length). Axial angle of the pedicle axis with the median sagittal plane (pedicle angle). Furthermore, this was determined as the angle between the pedicle axis and the midline of the vertebral body in the axial plane. Sagittal angle of the pedicle. This was determined as the angle between the pedicle axis and the superior border of the vertebral body in the sagittal plane.

The above parameters were measured using the DICOM computer software with a precision of 0.1mm and angle 0.1º by a senior radiologist.

Data management and statistical analysis

To ensure validity, measurement of all parameters was repeated three times and only one CT scan machine was used. Analysis of the data was done by computer program SSPS v17. Data was expressed as mean ± standard deviation for the group of male and female individuals. The data was presented in text and tables. The student t-test was employed for all statistical comparisons and $P< 0.05$ was considered statistically significant in all analyses.

Ethical considerations

All collected information was treated with confidentiality. The study was only carried out after approval by the Department of Orthopedics, Department of Radiology of Mulago, The school of medicine research and Ethical Committee (SOMREC) and permission by Mulago Hospital administrations.

RESULTS

During the study period, 99 **subjects** were enrolled of **these** 48 were females and 51 were males. The mean age of the participants was 53 years ± 16 yrs. (range 22-92 years), the majority of whom (45%) were in the 41-62 age group "Table 1"

In both males and females, the widest minimum horizontal pedicle diameter was located at L5 with a mean of 10.8 ± 2.8 for male, 11.3 ± 2.0 female for the right side and then 10.7 ± 3.0 for the males, 11.1 ± 1.9 for the females on the left side "Table 2 and 3".

The narrowest minimum horizontal pedicle diameter was located at L1 with a mean of 5.2±1.5 for the males of 4.6±1.3 for the females on the right and 5.2±1.5 for males and 4.6±1.3 for females on the left. There was a significant difference in the minimum horizontal diameters between L1-L3 among males and females with P values for L1=0.02, L2=0.03, L3=0.04 "Table 2 and 3".

Table 1: Demographic characteristics

Age Category (in years)	**Sex**		**Total**
	F	**M**	
22-40	11	11	22
41-60	20	25	45
61-92	17	15	32
Total	48	21	99

F = Female, M = Male.

Table 2: Morphometric measurements of the left pedicle.

Level (L)	**Horizontal Diameter Lt(mm)±SD**		**Vertical diameter Lt(mm)±SD**		**Axial angle Lt(degrees) ±SD**		**Sagittal angle Lt(degrees) ±SD**		**Chord length Lt(mm) ±SD**	
	M	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
L1	5.2±1.5	4.6±1.3	8.2±0.9	7.7±0.8	16.8±1.7	16.3±2.1	5.3±2.4	5.4±1.2	48.0±3.0	46.6±3.5
L2	5.5±1.6	4.8±1.4	8.4±0.9	8.2±0.7	16.9±2.2	16.8±2.1	5.3±1.8	5.1±1.1	49.2±3.1	47.7±2.8
L3	6.7±1.5	6.1±1.5	8.6±0.8	8.3±0.8	17.8±2.1	17.5±2.3	5.4±1.9	5.1±1.7	49.5±2.7	48.0±3.3
L4	7.8±1.8	7.5±1.4	8.0±0.8	7.7±0.9	19.2±3.1	18.5±2.1	4.4±1.1	4.4±1.0	47.4±2.9	46.6±3.0
L5	10.7±3.0	11.1±1.9	7.0±0.9	6.7±0.7	21.5±2.8	21.6±2.9	4.8±1.0	4.7±0.9	46.5±3.6	45.3±3.5

F = female, M = male, Lt = left.

Table 3: Morphometric measurements of the right pedicle.

Level (L)	Horizontal Diameter Rt (mm) ±SD		Vertical diameter Rt (mm) ±SD		Axial angle Rt (degrees) ±SD		Sagittal angle Rt (degrees) ±SD		Chord length Rt (mm) ±SD	
	M	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
L1	5.2±1.5	4.6±1.3	8.1±0.9	7.8±0.8	16.4±2.5	16.2±2.5	5.5±2.5	5.5±1.4	48.5±2.7	47.0±3.5
L2	5.5±1.6	4.9±1.4	8.4±1.0	8.2±0.9	16.7±2.1	17.1±3.1	5.2±1.7	5.1±1.0	49.4±3.2	47.8±2.6
L3	6.7±1.4	6.3±1.6	8.5±0.8	8.3±0.9	17.5±2.5	17.2±2.6	5.3±1.8	5.3±1.8	49.8±2.6	48.0±3.3
L4	7.8±1.9	7.6±1.5	8.0±1.0	7.8±0.9	19.2±3.2	18.1±2.1	4.3±1.0	4.4±1.0	47.9±2.8	46.7±3.2
L5	10.8±2.8	11.3±2.0	7.0±1.0	6.8±0.7	21.5±3.1	21.6±2.6	4.9±0.9	4.9±1.0	46.5±3.2	45.4±3.5

F = female, M = male, Rt = right.

There was a gradual and progressive increase in the vertical diameter from L1 with a mean value of 8.2 ± 0.9mm for males,7.7 ± 0.8mm for females on the left and then 8.1 ± 0.9mm for males ,7.8 ± 0.8mm for females on the right; to the L3 with a mean values of 8.6±0.8mm for males ,8.3 ± 0.8mm for the left and 8.5 ± 0.8mm for males and 8.3 ± 0.9mm for females on the right side and then a decrease to L5 with a mean of 7.0 ± 0.9mm for males,6.7 ± 0.7mm for females for the left and then 7.0 ± 1.0mm for males and 6.8 ± 0.7mm for females on the right side “Table 2 and 3”.

Chord length

The cord length increased from L1 to L3 with maximum values being 49.5 ± 2.7mm for males and 48.0 ± 3.3 for females on the left, 49.8 ± 2.6mm for males and 48.0 ± 3.3mm for females on the right side. The shortest chord lengths were at L5 with mean values of46.5 ± 3.6mm for males and 45.3 ± 3.5mm for females on the left, 46.5 ± 3.2mm for males and 45.4 ± 3.5mm for females on the right side “Table 2 and 3”.

The axial angles

There was a gradual increase in the pedicle axial angle from L1 to L5. The smallest angle was at L1 with means of 16.8 ± 1.7°for males and 16.3 ± 2.1° for females on the left side, 16.4 ± 2.5°for males and 16.2 ± 2.5° for females on the right side. The largest angles were at L5 with mean values of 21.5 ± 2.5°for males, 21.6 ± 2.9° for females on the left side and 21.5 ± 3.1° for males, 21.6±2.6° for females on the right side.

The Sagittal angles

The sagittal angles gradually decreased from L1 to L4 and then a slight increase at L5. The largest sagittal angles were at L1 with means of 5.3±2.4°for males and 5.4±1.2° for females on the left side and 5.5±2.5°for males and 5.5±1.4° for females on the right side. The smallest angles were at L4 with mean values of 4.4±1.1°for males, 4.4±1.0° for females on the left side and 4.3±1.0°for males, 4.4±1.0° for females on the right side.

Discussion

Transpedicular fixation of the lumbar spine with pedicle screws has become widespread and is now the mainstay of segmental fixation in the lumbosacral spine [7]. A detailed knowledge of pedicle size and dimension is key to posterior instrumentation of the spine through the pedicles.

The importance comes when the choice of screw is put into consideration as use of inappropriate screw size and length may lead to either breach of pedicle cortices hence failure of fixation or penetrating the vertebral body walls thus a potential risk to damaging the structures laying anteriorly namely the microvasculature [8] [9] [10] [11]. A pedicle screw also needs to be well oriented within the axis of the pedicle to include the largest available horizontal and vertical diameters for the fixation to be stable [12].

In this study, the pedicle dimensions compare well with figures published elsewhere [13] [8]. The parameters considered were the horizontal and vertical pedicle isthmus endosteal diameters, chord length, sagittal and horizontal angles and comparisons were made for both the left and right pedicles and then for male and female sexes.

Horizontal isthmus endosteal diameter

The oval shaped pedicle was generally narrowest in the horizontal plane though diameters were smaller for the female. When compared to other studies, the minimum horizontal endosteal pedicle diameters in this study are smaller [8] [14] . There was a significant difference between male and females. This corroborates well with several other studies [14]. This could be explained by the amount of activity level males have as compared to females. The posterior elements of the vertebral bodies, in particular, have a marked ability to undergo re-growth and remodeling [15] [16].

It can be fairly explained that pedicles if subjected to changing mechanical stresses with activity levels, they would probably show appropriate variations in strength (or diameters) and this can afford us the explanation of differences between males and females seen our study and earlier studies. This parameter is important because it is what determines the maximum pedicle screw diameter that can be accommodated since anything greater than this will cause pedicle breakage or thread cut out and this will lead to a failure of fixation [17].

The minimal pedicle isthmus diameter is very significant when selecting the diameter of the pedicle screw [18]. For purposes of safety of fixation, studies have shown that it is advisable to choose a screw diameter less than the isthmus endosteal width of the pedicle or within 80% of the isthmus width [14].

Vertical isthmus endosteal diameter

There was a gradual increase in the minimum vertical diameters from L1 to L5. This trend compares well with other studies though values in this study were relatively lower [5] [8] [19] [10]. The vertical diameter is generally wide and does little limit to the maximum diameter of the pedicle screw to be used especially in the upper lumbar spine.

Amonoo –kuofi et al showed no differences between right and left pedicles measurement and also sex though he related the larger vertical diameter of the pedicle of the 1st lumbar vertebra (in both males and females) as compared with the vertical diameters of 2nd and 3rd lumbar pedicles to the weight bearing functions [20].

One notable observation was that down to L5 the horizontal diameter increased much more compared to the vertical diameter suggesting that it would be worth considering in determining screw diameters in the lower lumbar vertebrae. Some researchers opine that the vertical diameter with its larger dimension and wider variations with age, contributes more to weight- bearing function than the horizontal diameter [20].

In pedicle screw placement, the pedicle lateral and medial walls are seldom affected because of their broadness distally hence dautnger of nerve compression is rare. Roy –Camille et al. And Gertzbein et al consider this to be due to the fact that there is a 2+2mm interval space between the pedicle wall and dural sac and 2mm of subarachnoid space hence the rarity of insults in the lower lumbar spine in pedicle screw fixation [21] [22].

Axial and sagittal angulation

The axial pedicle angle is the angulation of the pedicle in relation to the midline of the vertebrae and is important as regards to violation of the pedicle medial and lateral walls with the pedicle screws if they are inappropriately oriented. The axial (horizontal) pedicle angle was medial in the lumbar spine at the level of L5 and tending towards neutral by L1 i.e. The angle keeps on decreasing as one moves from L5 to L1. Similar results have been reported by others [5] [8].

When inserting a pedicle screw passing through the pedicle axis has the advantage of being within the isthmus of the pedicle hence good purchase and a good fixation with minimal fear of damage to the pedicle walls and the neural structures in their vicinity. Medially directed screws have a danger of breaching the medial wall of the pedicle and thus a risk to the dural sac and spinal cord while for the laterally directed screws threatened the lateral wall.

In the sagittal plane, the pedicles angled in an increasingly cephalad direction from L5 to l1with the largest angle found at l1about 6 degrees and the smallest atl5 about 5 degrees. This is comparable to the results from other studies [23]. The sagittal and transverse angles were compared for both sexes and the two sides and the male values were a little bigger than the female values however there was no significant statistical difference noted between the two sexes and this is comparable to previous studies.

The sagittal angles gradually decreased from L1 to L4 and then a slight increase at L5. Studies done in different races have yielded contrasting sagittal angles suggesting that differences may exist among populations. For example, in the Indian population the pedicles were directed cranially in the sagittal plane at all lumber levels except L5. Other studies had negative sagittal angles in their especially for L5 and L4 [23] [10].

Chord length

The pedicle chord length was measured as the distance between the posterior cortical entry point of the pedicle and the anterior vertebral cortex in line with the axis of the pedicle. This distance is of great importance in preventing anterior cortex perforation and possible injury to vital structures as this usually determines the length of screw to be used.

The longest cord length was noted at the L3 vertebrae level and the shortest was at L5 level. Similar patterns were reported from studies in Caucasian and Egyptian populations [5] [8]. Mitra et al reported a slightly different pattern with the shortest chord length at L1 [23].

The pedicle chord length in the lumbar region was seen to be longer in the upper vertebrae and generally reducing downwards. Bing et al reported that this coincided with weight increase and weight bearing and it also had the implication that as one went up the lumbar the less safe the pedicle screw fixation was [19].

Osteoporosis has the effect of making the pedicle walls thinning which makes the pedicle isthmus diameter wider and this may result in implant loosening which would warrant the need for augmentation either with bone cement or bone grafting. This can be partially addressed by inserting the screw as deep as possible as long as it does not injure organs anterior to the vertebral body. Studies show that deeper inserted screws withstand the largest number of cycles in the cephalad –caudad and medial-lateral direction before failure and screws purchasing the anterior cortex had greater pull out strengths than screws inserted to a lesser depth [13] [7].

Limitations of the study

The study was limited by the use of CT scans of only those who could afford part of the price of the CT scan. The study was also limited by the fact that we were only studying people who came to Mulago hospitals and we were not be able to get all the patients getting Orthopedic care to be included in the study

Conclusion

CT pedicle measurements are accurate indicators of the actual pedicle morphometry. The Ugandan lumbar pedicles measurements differ and are smaller in some aspects from the pedicles of other populations. The female pedicle dimensions are smaller than for the males and no difference exists between the left and right pedicles. The pedicle screw diameter, the screw length, and the angle of its insertion are better tailored according to the CT pedicle measurements of each patient prior to surgery. The pedicle screw length to be considered would be from 45mm to 50mm as appropriate for the Ugandan population. From this study, the appropriate pedicle screw sizes to use would be 6mm diameter screws for the upper lumbar and 8mm diameter screws for the lower lumbar vertebrae putting into consideration the horizontal and vertical diameter comparisons as one went down the lumbar vertebra.

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