A CT-BASED STUDY OF THE THORACIC SPINE PEDICLE AND PEDICLE-RIB UNIT MORPHOMETRY IN A KENYAN POPULATION

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ABSTRACT

Background: The use of pedicle screws in thoracic spine fixation is guided by the morphometric characteristics of the thoracic pedicle and thoracic pedicle-rib unit.
Objective: To document the dimensions of the thoracic pedicle and the pedicle-rib unit in a Kenyan population.
Methods: Demographic factors, thoracic pedicle dimensions and thoracic pedicle-rib unit dimensions of 97 patients were studied.
Results: The outer transverse diameter of the thoracic pedicles of T1 to T12 varied between 4.5mm and 8.4mm. The pedicle-rib unit diameter was 8.2mm larger. The thoracic pedicle chord length varied between 36.2m and 43.7mm. The pedicle-rib unit chord length was 12.7mm longer. The thoracic pedicle transverse angle decreased from 41.6^0 at T1 to 2.6^0 at T12. The thoracic pedicle-rib unit's transverse angle decreased from 48.6^0 at T1 to 20.4^0 at T12.
Conclusions: The optimal thoracic pedicle screw diameter size is 6.5mm. Optimal pedicle screw lengths are: 35mm at T1 to T5 level, 40mm at T6 to T11 levels and 45mm at T12 level. Optimal medial angulation of the screw during placement is: 40^0 at T1, 25^0 at T2, 15^0 at T3 to T5, 10^0 at T6 to T10, 5^0at T11 and 15^0 at T12.

Key words: Thoracic pedicle morphometry, Diameter

INTRODUCTION

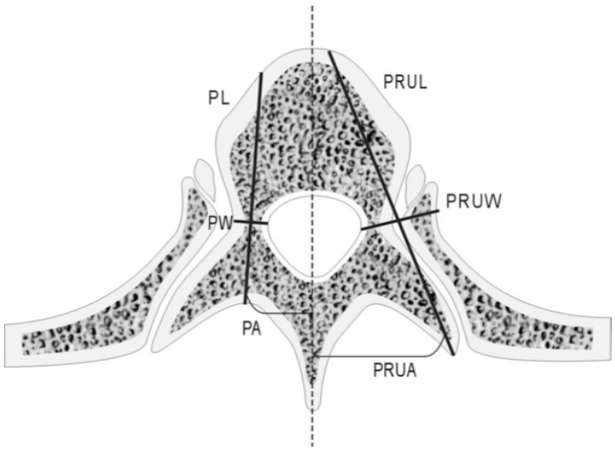
The morphometry of the thoracic pedicle and thoracic-pedicle rib unit has been documented in various studies, including American, Chinese, French, Malay, Korean, Greek and Indian among others (1-11). The characteristics of the thoracic pedicle and thoracic pedicle-rib unit guide the use of pedicle screws in spinal fixation. The size of the pedicle screw is determined by the transverse width at the isthmus and chord length of the thoracic spine pedicle and pedicle-rib unit. The actual placement of the screw during surgery in the axial plane is determined by the transverse angulation of the pedicle and pedicle-rib unit. This use of pedicle screw fixation in the spine is on the increase in Africa. However, no comprehensive data could be found in English literature concerning the morphometry of the thoracic spine pedicle and pedicle-rib unit in the African population, despite increased use of pedicle screw instrumentation in Africa. Consequently, this study sought to document the width, chord length and angulation of the thoracic pedicle and thoracic pedicle-rib unit, as measured in the axial plane; and their relation to patient demographic factors in a Kenyan population.

MATERIALS AND METHODS

Data collection: This was a cross-sectional study carried out at the radiology department of Moi Teaching and Referral Hospital. Institutional research and ethics approval was obtained prior to starting the study. Consent for the study was obtained in adults, while both consent and assent was obtained in children. All patients presenting for computerised tomography scanning of the thoracic spine and consented were recruited. Their demographic factors were recorded including the age, sex, height and weight. Patients whose age, height or weight could not be determined were excluded from the study. The subsequent CT scan images of the thoracic spine were studied. The CT scanner used in this study was the Siemens Somatom Perspective 32 slice scanner, and image slices were of 1.5mm thickness. The outer transverse diameter, chord length and transverse angle of each thoracic pedicle and thoracic pedicle-rib unit was measured and recorded. Patient's whose CT scan images demonstrated a pathology that interfered with the accuracy of measurement of the dimensions or that did not demonstrate the full extent of the thoracic spine from T1 to T12 were also excluded from the study.

The measurement method was adapted from Tian *et al* (12) as depicted in Figure 1. The measurements taken included: the pedicle transverse diameter at the isthmus (PW), the pedicle chord length (PL), the pedicle transverse angle (PA), the pedicle-rib unit transverse diameter at the isthmus (PRUW), the pedicle-rib unit chord length (PRUL) and the pedicle-rib unit transverse angle (PRUA); using the computer based measuring ruler ingrained in the CT scan machine software program.

Figure 1
Adapted from Tian et al, Spine(2010)



The precise location of the pedicle chord length (PL) was noted to be inconsistent with the above measurement method and therefore the measurement method was modified. The goal was to obtain the pedicle chord length along the longitudinal axis of the pedicle. Therefore, this modification involved drawing a line along each of the cortices of the pedicle. The pedicle chord length was then placed between and at the centre of these two lines along the long axis of the pedicle as shown in Figure 2

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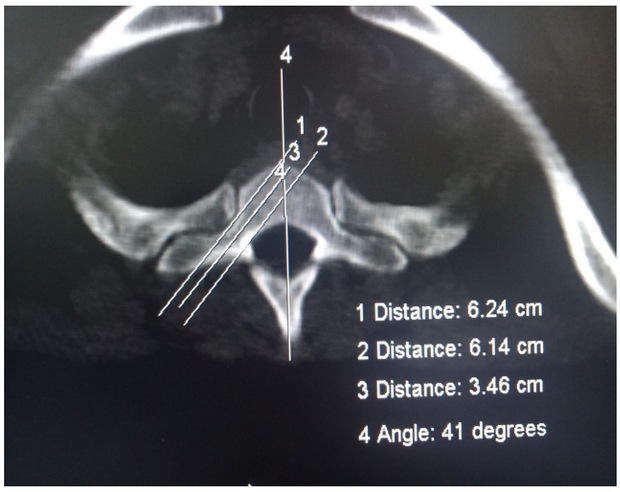
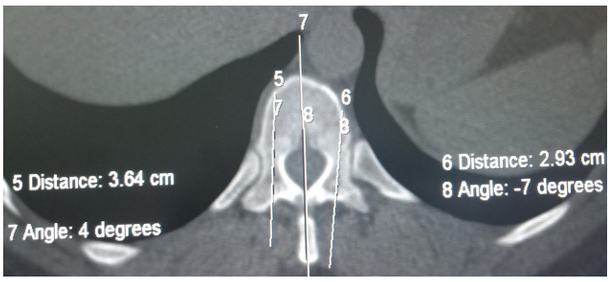
Figure 2
Measurement of the pedicle chord length along the axis of the pedicle



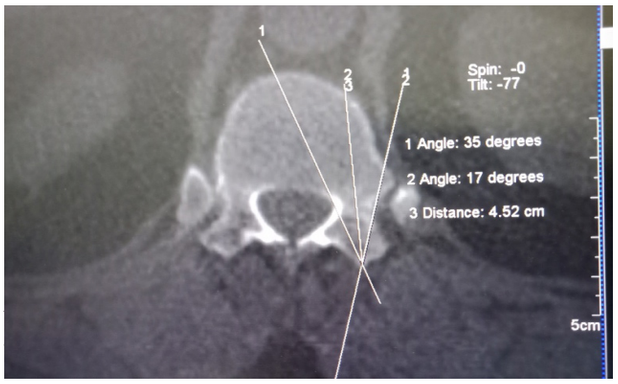
The above method demonstrated that some of the T12 pedicles were divergent. These measurements were recorded. However, this would give a suboptimal screw size and placement during surgery as shown in Figure 3.

Figure 3
Divergent T12 pedicle



Therefore, a modified T12 measurement method was employed. Two lines were drawn originating from the mamillary process tip. The first line was drawn along the most lateral extent possible for placement of a pedicle screw and the second line along the most medial extent possible for a pedicle screw. The resulting angle was bisected and this final third line represented the optimal screw path. It was then measured for pedicle chord length and transverse angle as shown in Figure 4.

Figure 4
Modified T12 measurements using the optimal pedicle screw path method



Data processing and analysis: The data obtained was coded and entered into a computer and analyzed using STATA/MP13. Means, medians, standard deviations and ranges were calculated. The results were compared with published studies using the student's t-test. Linear regression analysis was done to assess the influence of age, sex, height and weight; on pedicle width, pedicle chord length, pedicle-rib unit width and pedicle rib unit chord length.

RESULTS

At the Radiology Department in MTRH, 101 patients presented for Computer Tomography scanning (CT-scan) of the thoracic spine. Among this study population, there were 4 children aged 4, 4, 9 and 10

years that were excluded from the analysis, hence the analysis herein is based on 97 patients. The ages of the patients ranged from 17 years to 85 years with a mean of 45.2 (SD 16.0) years. About 50% of the patients were aged below 45 years (IQR 35, 55). The patients were distributed almost equally in terms of sex where females were 46 (47.4%). The weights of the patients were normally distributed and spread from 34.5kg to 100kg with a mean of 67.2 (SD 13.3) kg. Fifty per cent of the patients weighed below 68kg, (IQR 58, 76). Out of the total 97 patients, 33 (34%) reported weight loss at the time of presentation to the hospital for CT scan. The latter were excluded when comparing weight and other study variables. The height of the patients was skewed to the left, and distributed from 107cm to 190cm. The average height was 169.5 (SD 10.9) cm and a median of 172 (IQR 165, 176) cm.

For each thoracic pedicle and thoracic-pedicle-rib unit parameter, left and right side dimensions were taken, giving a total of 144 measurements on each patient and 13,968 measurements for the 97 patients. Comparing the left and right measurements for each pedicle parameter, it was noted that there was no significant difference. Therefore, a decision was made to combine both left and right measurements by assuming each side came from a separate individual, hence increasing the unit of analysis to 194. The results are summarized in Table 1.

Table 1

The mean dimensions of the thoracic pedicle and thoracic pedicle-rib-unit

Vertebra level	CT-based measurements					
	Pedicle			Pedicle-rib-unit		
	Width in mm (SD)	Chord length in mm(SD)	Transverse angle in Degrees (SD)	Width in mm (SD)	Chord length in mm (SD)	Transverse angle in Degrees (SD)
T1	7.8(1.24)	37.5(3.53)	41.6(6.20)	17.0(2.29)	45.7(4.06)	48.6(5.21)
T2	6.2(1.03)	36.2(3.57)	26.4(6.78)	16.0(2.13)	47.2(4.43)	36.3(5.69)
T3	5.2(0.94)	36.4(3.23)	16.6(4.95)	13.4(1.62)	50.4(4.23)	31.7(4.58)
T4	4.5(0.91)	38.1(3.84)	13.9(4.85)	12.6(1.58)	52.3(4.13)	30.4(4.47)
T5	4.6(0.98)	39.5(3.36)	12.4(4.70)	12.4(1.63)	54.5(4.43)	30.9(4.31)
T6	4.9(1.08)	40.4(3.71)	10.7(4.47)	12.6(1.55)	56.2(4.36)	30.4(4.24)
T7	5.2(1.13)	41.7(4.00)	9.3(4.38)	12.7(1.59)	57.6(4.66)	29.0(4.37)
T8	5.5(1.15)	42.9(3.75)	8.6(4.85)	13.1(1.62)	58.1(4.96)	26.2(4.87)
T9	5.9(1.17)	43.7(3.69)	8.9(4.97)	14.0(1.69)	57.8(5.36)	23.7(4.85)
T10	6.7(1.37)	43.3(4.53)	8.1(5.26)	15.0(1.72)	56.0(5.85)	22.8(4.36)
T11	8.0(1.62)	41.4(4.96)	5.3(5.46)	16.0(2.02)	51.4(5.77)	21.0(5.40)
T12	8.4(1.65)	41.4(5.44)	2.6(5.91)	16.2(2.46)	48.0(5.90)	20.4(7.79)

The smallest pedicle diameter was recorded at T6 measuring 1.9mm while the largest was found at T1 measuring 12.5mm. The mean pedicle width was at its peak at T12, and gradually decreased with cranial advancement to its lowest value of 4.5mm at T4, then progressively widened to an average of 7.8mm at T1. The preferred screw diameter for thoracic pedicle fixation is at least 4.5mm in diameter (13). While allowing a 1.0mm rim of bone around a screw, there were pedicles at all levels that would not accommodate a screw with a diameter of 4.5mm (Table 2). These small pedicles were more common in the mid-thoracic spine between T3 and T9 vertebral levels.

Table 2
Proportion of pedicles that would not accommodate a 4.5mm screw

Spine level	N	Proportion of pedicles <5.5mm wide
T1	194	4 (2.1%)
T2	194	54 (27.8%)
T3	194	112 (57.7%)
T4	194	171 (88.1%)
T5	194	159 (81.9%)
T6	194	134 (69.7%)
T7	194	112 (57.7%)
T8	194	96 (49.5%)
T9	194	65 (33.5%)
T10	194	32 (16.5)
T11	194	11 (5.7%)
T12	194	7 (3.6%)

The smallest pedicle-rib unit transverse diameter was realized at T6 of 7.4mm, while the largest pedicle-rib unit transverse diameter found was at T1 measuring 23.7mm. The mean pedicle-rib unit transverse diameter was at its peak at T1 of 17.0mm and gradually decreased to its lowest value of 12.4mm at T5, then progressively widened to an average of 16.2mm at T12. The mean thoracic pedicle-rib unit transverse diameter was larger than the corresponding mean thoracic pedicle diameter at all levels by 7.5mm to 9.8mm (average 8.2mm).

The shortest chord length of a pedicle was realized at T11 of 21.6mm, while the longest pedicle chord length found was at T10 measuring 62.6mm. The mean pedicle chord length was at its peak at T9 (43.70mm), and gradually decreased to its lowest value of 36.2mm at T2. The shortest pedicle-rib unit chord length of a pedicle was realized at T12 of 11.2mm, while the largest pedicle chord length found was at T9 measuring 69.8mm. The mean pedicle-rib unit chord length was at its peak at T8 (58.1mm), and gradually decreased cranially to its lowest value of 45.7mm at T1. It also decreased caudally from T8 level to a T12 value of 48.0mm. The mean pedicle-rib unit chord length was longer than the corresponding mean pedicle chord length by 6.6mm to 15.9mm (average 12.7mm).

The smallest pedicle transverse angle of -15.3^0 was located at T12 while the largest was 57.4^0 at T1. This lateral angulation (negative transverse angle measurement) was demonstrated between T8 and T12 in 67 samples (34.5%). The largest mean pedicle transverse angle was 41.6^0 at T1. A sharp decrease in angulation by almost half was noted at T2, followed by a gradual decrease to the lowest angle of 2.6^0 at T12. On the other hand, the largest transverse angle of the pedicle-rib unit was at T1 measuring 66^0 while the smallest was -5^0 found at T12. The mean pedicle-rib unit transverse angle was more predictable, demonstrating a gradual decrease from 48.0^0 at T1 to 20.0^0 at T12.

Modified T12 level measurements: Divergence (lateral angulation) of the pedicle, as shown by a transverse angle of less than zero degrees, was found in 46% of the T12 pedicles. The optimal screw path method was chosen as the best method of determining the chord length and transverse angle; and the results are as shown below in Table 3.

Table 3
Modified T12 pedicle measurements

	Chord length		Transverse angle	
	Range in mm	Mean in mm (SD)	Range in degrees	Mean in degrees (SD)
T12 pedicle measurement along the pedicle axis	24.9 – 53.6	41.40(5.44)	-15.3 – 26.0	2.63(5.91)
Modified T12 measurement using the optimal screw path method	40.8 – 63.1	50.29(4.40)	1.0 – 27.0	12.89(5.24)

Association between age, sex, height and weight of the subject; and the size of the thoracic pedicle: Linear regression analysis done in this study demonstrated that the size of the thoracic pedicle was influenced by the age and sex of the subject/patient. The pedicle width on linear regression increased by 0.004 - 0.019mm per year increase in age. This dimension was also larger in males than females by 0.251- 0.954mm, depending on the vertebral level. These coefficients were larger in the bigger pedicles and smaller in the smaller pedicles. The thoracic pedicle chord length increased by 0.039- 0.085mm per every year increase

in age; and was longer in males by 1.856-3.809mm compared to females. The subject's height and weight did not influence these two measurements. Neither did age, sex, height and weight demonstrate association with the thoracic pedicle transverse angle.

Association between age, sex, height and weight of the subject; and the size of the thoracic pedicle-rib unit: Similarly, the pedicle-rib unit width increased by 0.014 – 0.032mm per year increase in age; and was larger in males compared to females by 1.221– 1.984mm. The pedicle-rib unit chord length increase by a margin of 0.033- 0.088mm per every year increase in age, and was larger in males than females by 1.650- 5.465mm. The pedicle-rib unit width and chord length was not influenced by the subject's height and weight. There was no relationship between the pedicle-rib unit transverse angle and age, sex, height or weight.

DISCUSSION

*The length, width and transverse angle; of the thoracic pedicle/pedicle-rib unit***:** The mean thoracic pedicle widths as measured on CT scan images demonstrated a similar cranio-caudal trend to that seen in published literature (1-11). The narrowest pedicles were located at T4 level and the widest pedicle width occurred at the ends of the thoracic spine i.e. at T12 and T1 thoracic spine levels. The mean pedicle widths obtained from this study are not significantly different from those found by Zindrick *et al* (4), Ugur *et al* (8) and Roop *et al* (11). However, the dimensions were significantly larger than those found in previous cadaveric data in a Kenya population (14). The latter investigation used dry bone specimens of people that were alive in the 1950s from the central region of the country. Further comparison of the current CT-based dataset obtained from the people of central Kenya origin and that obtained from the dry-bone specimens, maintained this difference. Measurement error was deemed unlikely, pointing to a possible generational change in the size of the pedicle. Improved living standards and nutrition over the last 60 years may have led to larger body frames in the current population. This is unlike the finding by Yu *et al* (3) whose data demonstrated that their population's thoracic pedicle widths have remained stable over the last century.

The thoracic pedicle-rib unit width demonstrates a similar trend with the narrowest pedicle located at T5. The mean thoracic pedicle-rib unit is on average 8.2mm larger that the corresponding mean thoracic pedicle width discussed above, and can therefore accommodate a wider pedicle screw during surgery. The results from our CT-based study demonstrate significantly smaller widths compared to the works of Kim *et al* (7) in a Korean population.

The thoracic pedicle chord length and thoracic pedicle-rib unit chord length trend reported by literature is similar to that demonstrated by the current study. However, the thoracic pedicle chord lengths were significantly longer than those found by Roop *et al* (11), and Kim *et al* (7); but comparable to the lengths found by Gangadhara (10). The thoracic pedicle-rib unit chord lengths were significantly smaller than those found by Kim *et al* (7).

The thoracic pedicle and thoracic pedicle-rib unit transverse angles decreased with caudal advancement from T1 to T12, a finding that is similar to published literature. However, no conclusions could be drawn from comparisons of the mean values with other studies in literature. The modified T12 measurement using the optimal screw path method was found in this study to eliminate negative transverse angles and give longer pedicle chord lengths. The mean transverse angle is similar to that recommended by Kim and Lenke (15). This would give better screw purchase and enhanced fixation.

The association between age, sex, height and weight of the subject; and the size of the thoracic pedicle/ pedicle-rib unit: Similar to literature, age and male sex were positively correlated with pedicle and pedicle-rib unit size (width and chord length), but no correlation was found with the pedicle and pedicle-rib unit transverse angle. Unlike the findings by Yu *et al* and Zhuang *et al*, the patient's weight and height did not influence any of the thoracic pedicle and thoracic pedicle-rib unit parameters in the current study (3,16). Yu *et al's* (3) investigation utilized cadaveric data as opposed to CT scan images. This presents an avenue for further investigation.

Implications in surgery: In this study, all levels of the thoracic spine had some pedicles that could not accommodate a 4.5mm screw. It is the considered opinion of the investigators that the screw placed within the narrower mid-thoracic pedicles is situated in the pedicle-rib unit, rather than the pedicle per se, as suggested by McLain *et al* (13). With this in mind, a 6.5mm diameter pedicle screw is recommended for use at all thoracic spine levels. Larger diameter screws should be reserved for revision surgery cases.

The pedicle screw length should be approximately 5mm shorter than the anticipated pedicle chord length so as to avoid penetration of the anterior cortex which could result in injury to viscera. On the basis of the mean dimensions obtained from this study, recommended pedicle screw lengths include: 30mm at T1 to T4 level, 35mm at T5 to T8, 40mm at T9 to T11 levels and 45mm at T12 level. The recommended average medialization of the screw during placement would be 40^0 at T1, 25^0 at T2, 15^0 at T3 to T5, 10^0 at T6 to T10, 5^0 at T11 and 10^0 at T12.

CONCLUSIONS

Based on the results of this study, the authors recommend that the optimal pedicle screw diameter for use in thoracic spine fixation in adults is 6.5mm at all levels and reserve larger (>6.5mm) diameter screws for revision surgery. This screw following placement would lie within the thoracic pedicle in the larger caudal and cranial vertebrae; and would inevitably be in the pedicle-rib unit in the narrower mid-thoracic vertebral pedicles. Further studies to characterize this phenomenon are required. The optimal pedicle screw lengths are: 30mm at T1 to T4 level, 35mm at T5 to T8, 40mm at T9 to T11 levels and 45mm at T12 level. The recommended average medial angulation of the screw during placement is: 40^0 at T1, 25^0 at T2, 15^0 at T3 to T5, 10^0 at T6 to T10, 5^0at T11 and 10^0 at T12.

CONFLICT OF INTEREST

The authors declare they have no conflicts of interest that are directly or indirectly related to this research.

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