MORPHOMETRY OF THE THORACIC PEDICLE AND THE PEDICLE-RIB UNIT: A REVIEW OF LITERATURE

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ABSTRACT

Background: The pedicle is the most commonly used site in spinal fixation. The size of the pedicle screw utilized is determined by the dimensions of the pedicle. The purpose of this review is to summarize the available English literature on thoracic pedicle morphometry.
Materials and methods: PubMed search with the mesh term "thoracic pedicle morphometry measurements" and "pedicle-rib unit morphometry measurements" found 25 relevant articles.
Results: The transverse width of the thoracic pedicle is narrowest at the mid-thoracic region. The chord length increases with caudal advancement, and is longest in the lower thoracic spine. The transverse angle of the thoracic pedicle is neutral or divergent at the lower thoracic spine, while it is most convergent in the upper thoracic spine.
Conclusions: Linear thoracic pedicle dimensions are influenced by age, gender, height, weight and spinal level. Angular dimensions are influenced by spinal level only. Pedicle screw size choice and application is therefore guided by these factors. Pre-operative CT scanning of the thoracic spine is highly recommended in surgical planning.

Key words: Thoracic vertebra pedicle, Pedicle-rib unit, Morphometry

INTRODUCTION

Pedicle screw instrumentation is the most common method of spinal fixation in the world today and provides far superior fixation to all other preceding methods (1). The size of the pedicle screw used and its placement in the pedicle is influenced by the pedicle's morphometry, which includes the pedicle's size and angulation. Improper screw selection and placement in the thoracic spine compromises fixation and is a threat to adjacent critical structures, including the lungs, blood vessels and neural structures (2, 3).

Various authors have studied the thoracic pedicle anatomy. Considerable variability in the dimensions has been noted both within the individual thoracic spine specimens, amongst different specimens and in different populations (4-16). No comprehensive amalgamation of all this data could be found in English literature that could aid an investigator to gain an overall insight of the findings. In view of this, the authors sought to identify all such data in English literature and discuss it in this review article.

MATERIALS AND METHODS

A PubMed search was done using the terms "thoracic pedicle morphometry measurements or pedicle-rib unit morphometry measurements" and found 271 abstracts. The parameters of interest were: transverse width at the isthmus, transverse angle and; chord length as measured along the longitudinal axis of the pedicle/ pedicle-rib unit. Twenty five relevant articles were found to fulfil these criteria and included in this review.

RESULTS AND DISCUSSION

THORACIC PEDICLE MORPHOMETRY

Pedicle transverse diameter

The transverse diameter of the thoracic pedicle (pedicle width) measured at the isthmus determines the largest screw diameter that can be placed in the pedicle. The pedicle height is consistently larger than the pedicle width. The largest thoracic pedicle transverse diameter is found at the ends

of the thoracic spine either at the first thoracic vertebra (T1), the eleventh thoracic vertebra (T11) or the twelfth thoracic vertebra (T12). This outer diameter on average varies from 7.7mm to 9.8mm. The narrowest diameter is found at T4 or T5, and measures 3.6-5.9mm. The larger diameters were found in American and French studies, while the smaller diameters were found in Asian, Indian, Chinese, Malaysian and Turkish populations. The general trend is to have large transverse diameters at the lower quarter (T12 to T10) of the thoracic spine, followed by a progressive decrease up to the middle (T6, T5, T4) of the thoracic spine and a progressive increase in pedicle caliber in the top quarter up to the T1 level (Table 1).

The combined medial and lateral cortical thickness varies from 1.63mm to 2.76mm (3,15). As a result, the average transverse inner (endosteal) diameter of the thoracic pedicle can be as small as 3.0 mm at the mid-thoracic level. Since the transverse diameter is larger in males by 1.4±0.2mm, measures of this inner diameter of the thoracic pedicle in females can be as low as 2.7mm at T5 vertebral level (7,17). However, the real minimal outer pedicle diameter runs obliquely and may not be appreciable in the thoracic spine CT scan image. This parameter is 0.2-0.5mm smaller than the smallest outer transverse diameter; the smaller values being obtained in the T4 and T5 levels while the larger values are found at the ends of the thoracic spine (10,18).

In addition to gender and thoracic spine level; age, body height and body weight are the significant influencers of pedicle width. In the upper thoracic spine, pedicle width increases with age at a rate of 0.009-0.018mm/year; while in the lower thoracic spine it increases at 0.009-0.015mm/year. The pedicle width increases at 0.80-2.42mm/m of body height in the upper thoracic spine and at 1.12-2.60mm/m in the lower thoracic spine. The body weight relationship with pedicle width is 0.006-0.010mm/kg in the upper thoracic spine, while in the lower thoracic spine it is 0.008-0.021mm/kg increase in body weight. Then effect of race is not consistent (13, 14).

Pedicle chord length

The chord length is measured from the posterior cortex of the vertebra to the anterior cortex of the vertebra along the longitudinal axis of the pedicle. This represents the maximum length of the path that a pedicle screw would take following insertion into the pedicle (5). The shortest chord length is found at the upper quarter of the thoracic spine at either T1, T2 or T3 (though the most frequent location is T1). This measurement varies from 24.60mm to 34.76mm, and tends to increase progressively caudally by 0.3-3.0mm up to the level with the longest pedicle chord length in the lower thoracic spine at T8, T9, T11 or T12; measuring 35.60-45.4mm. From this point, the decrease to the smallest pedicle chord length is within 7mm (Table 2).

Table 1

Pedicle transverse diameters from various studies

Study	Datir & Mitra (5) Indian N=18		Zindrick *et al* (16) American N=20-42	Scoles (19) American N=25		Liau *et al* (8) Malaysian N=180		Gangadhara (6) Indian N=20	Singh *et al* (10) N=100
Thoracic level									31.8
	DIR	CT				M	F		
T1	29.9	31.1	36.9	32.0	29.1	34.76	32.30	25.8	31.88
T2	29.9	31.0	35.7			36.65	33.41	20.79	34.33
T3	30.3	28.8	37.7	31.6	30.1	36.98	34.65	8.12	36.15
T4	31.7	31.8	38.5			37.44	35.84	15.4	37.96
T5	33.7	34.7	41.9			38.41	36.28	13.06	39.26
T6	34.8	36.1	42.1	37.7	35.7	39.21	36.89	12.25	41.04
T7	34.4	36.8	44.6			39.75	37.16	11.22	43.41
T8	34.7	39.8	45.4			40.02	37.37	10.09	43.74
T9	35.5	40.6	45.2	41.9	38.9	39.03	37.18	8.78	44.48
T10	36	38.8	44			39.09	36.40	-1.4	43.87
T11	37.3	38.6	41.8			37.85	34.84	-10.01	43.83
T12	34.7	40.1	38.6	43.3	42.0	37.55	34.93		44.57

Table 2

Pedicle chord length from various studies

Study Race Thora-cic level	Panjabi *et al* (9) American N=12	Zindrick *et al* (16) American N=24-36	Yu *et al* (14) American N=503	Datir & Mitra 5 Indian N= 18 DIR	 CT	Ugur *et al* (11) Turkish N=20	Vaccaro *et al* (12) Central Asia/North America N=36	Liau *et al* (8) Mala-ysian N=180	Chaynes *et al* (4) French N=10	Kim *et al* (7) Korea N=73	Zhuang *et al* (15) Chinese N=126	Gangad-hara (6) Indian N=20	Roop *et al* (10) Indian N=100
T1	8.5	7.9	8.65	7.3	5.8	6.7		7.97	8.3	8.1		7.72	6.98
T2	8.2	7.0	7.08	6.3	5.4	6.2		6.69	6.5	6.1		6.22	5.62
T3	6.8	5.6	5.77	5.2	5.4	5.3		5.32	5.9	4.6		5.03	4.43
T4	6.3	4.7	5.10	4.8	3.6	4.6	4.5	4.27	5.4	4.2		4.53	3.90
T5	6.0	4.5	5.07	4.7	4.0	4.7	4.4	4.42	4.9	4.3		4.22	3.93
T6	6.0	5.2	5.38	5.0	4.0	4.9	4.6	4.64	5.1	4.7		4.58	4.28
T7	5.9	5.3	5.66	5.4	4.4	5.3	4.7	4.77	5.7	4.8	4.65	4.82	4.77
T8	6.7	5.9	5.98	5.4	4.5	5.7	5.1	4.87	6.4	5.1	5.02	5.33	4.95
T9	7.7	6.1	6.53	5.9	5.0	6.2	5.8	5.27	6.4	5.2	5.37	6.1	5.59
T10	9.0	6.3	7.78	6.7	5.7	6.4	6.7	5.99	7.4	6.3	6.35	6.3	6.66
T11	9.8	7.8	9.31	8.2	7.4	7.8	8.0	6.78	9.3	7.9	7.78	7.8	7.55
T12	8.7	7.1	9.19	8.7	7.7	7.9	7.8	7.16	8.9	7.9	8.3	7.1	7.88

Pedicle transverse angle

The pedicles in the lower thoracic spine at T11 and T12 level are either neutral or divergent (average transverse pedicle angle measuring 0^0 to -4.2^0). Cranial to these levels, the thoracic pedicles are convergent. The transverse pedicle angle therefore increases progressively with cranial advancement but does not exceed 10^0 up to T4. The studies by Scoles *et al* (19), Panjabi *et al* (9) and Singh *et al* (10) measured slightly larger figures, though still less than 20 degrees between T10 and T4. An acute increase in convergence occurs in the upper three thoracic vertebrae with a maximum transverse pedicle angle of 26.6^0-31.8^0 recorded at T1 (Table 3).

THORACIC PEDICLE-RIB UNIT MORPHOMETRY

Transverse diameter

The pedicle-rib unit is an alternative pedicle fixation point. The general trend in the transverse diameter of the pedicle rib unit is like that of the thoracic pedicle with cranial advancement from T12 to T1. However, it is much larger by 7-14mm and can

Table 3

Pedicle transverse angles from various studies

Study	Datir & Mitra (5) Indian N=18 DIR	 CT	Zindrick *et al* (16) American N=20-42	Scoles (19) American N=25 M	 F	Liau *et al* (8) Malaysian N=180 M	 F	Chaynes (4) French N=14	Singh *et al* (10) Indian N=100	Panjabi *et al* (9) American N=12
T1	30	27	26.6	29.8	26.4	27.75	28.09	27.5	31.8	27.1
T2	19	18	19.1			17.85	18.16	17.3	25.8	28.6
T3	12	10	14.6	15.3	15.5	11.23	10.71	13.0	20.79	19.4
T4	6	7	12.6			8.14	7.80	8.1	8.12	19.5
T5	4	5	9.4			6.90	6.07	6.8	15.4	15.6
T6	3	5	9.6	10.2	10.9	5.58	5.28	6.7	13.06	16.4
T7	1	4	8.7			4.32	4.39	7.2	12.25	20.7
T8	1	2	8.1			3.51	3.76	7.1	11.22	19.6
T9	1	2	7.6	10.3	9.2	2.64	2.88	0.9	10.09	14.8
T10	1	3	4.6			1.26	1.27	7.7	8.78	12.4
T11	0	0	1.2			-0.24	0.01	0.8	-1.4	13.1
T12	0	0	-4.2	11.6	9.5	-0.58	-0.40	2	-10.01	9.8

therefore accommodate a bigger diameter screw. The largest mean transverse diameters have been recorded at T1 measuring 19.3mm and followed by the T11 and T12 areas with diameter readings of 17.3-18.7mm. The narrowest diameters are at the T4 and T5 areas measuring 13.5mm (Table 4).

Chord length

The general trend described by Husted *et al* (20) was a progressive decrease in the pedicle-rib unit chord length from T12 (63.0mm) to T1 (44mm). Recently, a Korean study demonstrated a gradual increase in this the pedicle-rib unit length from T12 level (55mm) to the T8 level (60mm) followed by a gradual decrease to T1 with a minimum mean length of 46.2mm (Table 4).

Transverse angle

Unlike the transverse angle of the pedicle, the transverse angle of the pedicle-rib unit is convergent at all levels. This measures on average 20.4^0 degrees at T12 with a progressive increase to 32.1^0 degrees at T3. Much larger convergence is noted in the upper two thoracic vertebrae with the largest being 46.2^0 degrees at T1 (Table 4).

THE IMMATURE SPINE

The size of the thoracic pedicle in the immature spine is determined by the age of the individual and the vertebral level. The pedicle is proportionately smaller in relation to the adult pedicle, while the influence of the vertebral level parallel's that seen in the adult thoracic pedicle. The pedicle width is significantly smaller than the pedicle-rib unit's width. The thoracic pedicle's chord length increases with age by approximately 70% between 3-5 years and adulthood. The average chord length of the thoracic pedicle is also significantly smaller than the pedicle-rib unit's chord length. Transverse angle measurements of the thoracic pedicle and pedicle-rib unit of the immature spine are like those found in adult cases (21, 22).

Age, and by inference growth, has a profound effect on the linear measurements of the pedicle and pedicle rib-unit; but has no effect on the angular measurements. The individual's gender has minimal influence on pedicle width; as opposed to the more significant influence on the pedicle chord length, pedicle-rib unit width and pedicle-rib unit chord length (21, 22).

SURGICAL IMPLICATIONS ON THE PEDICLE SCREW SIZE

Based on the various studies, appropriate screw sizes have been recommended. The appropriate screw should be the largest diameter possible to improve purchase and should also be confined within the pedicle and vertebral body to avoid injury to surrounding tissues. The maximum pedicle screw diameter applicable is limited by the transverse diameter of the pedicle's isthmus while

Table 4

Pedicle rib unit transverse diameter, angle, and chord length of data from various studies

	Transverse diameter		Chord Length		Transverse angle
	Husted *et al* (25) N=2-6	Kim *et al* (7) Korean N=958 vertebrae	Husted *et al* (25) N=2-6	Kim *et al* (7) Korean N=958 vertebrae	Kim *et al* (7) Korean N=958 vertebrae
T1		19.3		46.5	46.1
T2	17.2	17.5	43.4	50.0	37.6
T3	14.9	15.2	46.6	49.2	32.1
T4	14.2	13.9	49.4	54.9	29.5
T5	13.9	13.7	51.6	56.9	29.2
T6	14.2	14.2	54.8	58.8	27.8
T7	14.4	15.0	55.2	60.2	26.7
T8	14.4	15.4	56.1	60.3	26.2
T9	15.7	16.2	58.4	60.1	25.2
T10	16.9	17.1	60.0	59.3	23.9
T11	17.4	17.9	59.7	56.5	22.2
T12	16.1	18.7	61.8	55.0	20.4

the maximum length permissible is determined by the chord length. If the screw diameter exceeds 80% of the diameter of the pedicle isthmus, the pedicle will fracture; while a screw that perforates the anterior vertebral cortex risks intra-thoracic visceral injury (23).

Gangadhara *et al* (6) recommended the following pedicle screw sizes in adults as shown in Table 5. McLain recommends screws that are 5mm longer than these. Most surgeons are concerned about the strength of the smaller screw sizes and the possibility of implant failure. Consequently, there is a preference for standard screw sizes of 4.5mm or 5mm diameter as minimum permissible sizes. Clearly, these screws do not fit in the narrower pedicles of the mid-thoracic spine. It is possible that the pedicles are dilated in the process of screw placement to accommodate the screw or the screw is placed in the "in-out-in" manner that routinely breaches the lateral cortex. The alternative is an extra-pedicular placement of the screw in the larger pedicle-rib unit (24, 25).

Table 5

Gangadhara's determined values of transpedicular screw parameters after standardization

Vertebral level	Screw parameters after standardization	
	Diameter	Length
T1	5-6	25
T2	5-5.5	25
T3	3.5-4	25
T4	3-3.5	30
T5	3-3.5	30
T6	3.5-4	30
T7	3.5-4	35
T8	3.5-4	35
T9	3.5-4	35
T10	5.5	35
T11	5.5-6	35
T12	5.5-6	35

In children, the much larger thoracic pedicle-rib unit is more amenable to instrumentation than the thoracic pedicle per se. The pedicle height is the limiting dimension in this extrapedicular technique and is usually more than 5mm, 6mm, and 7mm for the age groups 3-8 years, 9-11 years, and 12-14 years respectively. Therefore, screw diameters of 5-7mm would be acceptable. Screw lengths of 20-30mm, 30-40mm, and 35-45mm for age groups 3-5 years, 6-11 years, and 12-15 years, respectively are recommended. In all age groups, a transverse angle of 45^0 at T1, 37^0 at T2, with a gradual decrease from 31^0 at T3 to 25^0 at T9, and 240 for the rest below T9 is reasonable (21, 22).

The data that has been used in this study represents the mean values from various studies to enable reasonable deductions to be made. The absolute values of the range would give the upper and lower limits of the specimens. There is clearly extreme variability in the pedicle width dimensions and therefore the use of a pre-operative CT scan, as recommended by previous authors is highly emphasized in thoracic spine pedicular instrumentation (17,25). This review article serves as a guide of the common expected pedicle dimensions.

CONCLUSIONS

The transverse width of the thoracic pedicle is narrowest at the mid-thoracic region. The chord length increases with caudal advancement, and is longest in the lower thoracic spine. The transverse angle of the thoracic pedicle is neutral or divergent at the lower thoracic spine, while it is most convergent in the upper thoracic spine. The linear dimensions are influenced by age, gender, height, weight and spinal level. Angular dimensions are influenced by spinal level only. Pedicle screw size choice and application is therefore guided by these factors. Pre-operative CT scanning of the thoracic spine is highly recommended for surgical planning.

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