Computed tomographic morphometry of thoracic pedicles: safety pedicle parameter measurement of the Chinese immature thoracic spine

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Abstract Our objective was to quantify the morphometric characteristics of the pedicles of the Chinese immature thoracic spine. A total of 120 patients aged 5–14 years underwent standard thoracic computed tomography (CT). The patients were grouped according to age: group 1 (5–8 years of age), group 2 (9–11 years of age) and group 3 (12–14 years of age). Images were reformatted, and multiplanar reconstructions were used to attain images of thoracic pedicles on sagittal, coronal and transverse planes. The measurements included the inner and outer pedicle diameters on the transverse plane, pedicle sagittal diameter, pedicle length and the pedicle angle on the transverse. (1) Pedicle diameters on the transverse plane decreased gradually from T1 to T4 and increased gradually from T5 to T12. The shortest transverse diameter of the thoracic pedicle was T4 or T5. (2) The sagittal diameter was significantly larger than the transverse diameter except at T1. (3) The length of the pedicle from the posterior cortex to the anterior cortex of the vertebra increased from T1 to T12. (4) The pedicle angle decreased gradually from T1 to T8 and became negative below the level of T10. The length of the pedicle changed with age significantly, but the pedicle angle changed with age insignificantly. The success of transpedicular fixation requires a better understanding of morphological features at different ages and reasonable selection of the diameter, length and direction of the pedicle screws based on X-ray and CT films.

Résumé Quantifier les caractéristiques morphométriques des pédicules de la colonne thoracique en croissance. 120

patients âgés de 5 à 14 ans ont bénéficié d'une radiographie du thorax standard avec tomographie. Les patients ont été regroupés selon leur âge: groupe 1 de 5 à 8 ans, groupe 2 de 9 à 11 ans et groupe 3 de 12 à 14 ans. Les images ont été reformattées avec une reconstruction sur le plan frontal, transversal et sagittal. Les mesures ont inclus les dimensions du pédicule mesuré sur les coupes transversales, sur les coupes sagittales et ainsi que la longueur du pédicule et son angle. le diamètre pédiculaire dans le plan transversal diminue progressivement de T1 à T4 et augmente progressivement de T5 à T12. Sur la coupe transversale, le pédicule thoracique, le plus court se situe de T4 à T5 (Résultat du groupe 1). Résultat du groupe 2: le diamètre sagittal est plus important que le diamètre mesuré transversalement sauf en T1. Pour le groupe 3: la longueur du pédicule va en augmentant de T1 à T12. 4ème, l'angle pédiculaire diminue progressivement de T1 à T8 et devient négatif en dessous de T10. La longueur du pédicule change de façon significative avec l'âge sans changement significatif de l'angle pédiculaire. La fixation transpédiculaire nécessite de bien comprendre ces éléments morphologiques en fonction de l'âge, la sélection des pédicules se faisant sur la radio et sur le scanner.

Introduction

The use of pedicle screws as fixation devices for posterior spinal fusion surgery has become increasingly popular worldwide. They offer rigid segmental fixation after decompression and arthrodesis for various disorders of the spine, including scoliosis, spondylolisthesis, fractures, tumours and iatrogenic or degenerative instability, etc. Most anatomical studies on the morphology of the thoracic pedicles have been reported in a white population, with a few reports in Asian patients. Various authors have shown

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that no significant statistical difference exists between data obtained from computed tomography (CT) scans and direct cadaveric measurements. The aim of this study was to assess the pedicle anatomy in a Chinese population based on CT scans. Previous studies had shown significant interracial differences of thoracic pedicle morphometry [2, 4, 10]. Therefore, a complete morphometry database of the thoracic pedicle is needed to determine the safety margin of transpedicular fixation in our population.

Materials and methods

We evaluated the CT scans of Chinese ethnic patients who were treated in our institution between January 2002 and December 2007. The patients who were between 5 and 14 years old were chosen through a stratified random sampling method from the children's hospital registry. Those who had thoracic spinal abnormalities (congenital deformity, trauma, primary or secondary tumour) were excluded. Axial CT images of each patient were taken using a General Electric CT scanner (Philips Secura 16-slice, Philips Medical Systems, Eindhoven, the Netherlands) with an axial slice at a 2-mm interval.

Measurements were taken for each thoracic level using the methods described by Vaccaro et al. [11]. We measured the following dimensions: (1) transverse inner pedicle diameter (Fig. 1), (2) transverse outer pedicle diameter (Fig. 1), (3) sagittal pedicle diameter (Fig. 2), (4) pedicle length (Fig. 1) and (5) transverse pedicle angle (Fig. 3).

Measurements were repeatedly made by two investigators to assure credibility of the evaluation. Three measurements were taken for each parameter at the isthmus and their averages were calculated. They were grouped according to age (5–8, 9–11 and 12–14 years), and the gender differences in parameters were analysed using the *t*-test. The age differences in parameters were analysed using the rank

Fig. 1 The transverse diameter (the medial-lateral inner and outer cortical width of the pedicle) measured at the isthmus. The pedicle length from the posterior cortex of the pedicle to the posterior longitudinal ligament along the axis of the pedicle

Fig. 2 The sagittal pedicle diameter (the superior-inferior cortical height) measured at the isthmus

correlation (Spearman's rank correlation). The results were then compared with other published studies.

Results

Transverse inner and outer pedicle diameters

The diameters showed a decreasing dimension from T1 to T4 followed by an increasing dimension from T5 to T12 in all groups (Table 1). The narrowest diameter occurred at T4 or T5 (Fig. 2). There were no significant differences between male (M) and female (F) patients at each level ($p > 0.05$). The factor of age appeared to present an associative effect along aspects of transverse width (r_s range: M group 0.387–0.594, F group 0.335–0.513, $p < 0.05$).

Sagittal diameters

The diameters showed an increasing dimension from T1 to T12 (Table 2). The biggest diameters were at T1. The sagittal

Fig. 3 The transverse pedicle angle measured from the midline to the mid-axis of the pedicle

Table 1 Transverse inner and outer pedicle diameters (mm)

	5–8 years		9–11 years		12–14 years	
	M	F	M	F	M	F
T1	3.19±0.63 6.06±0.92	2.95±0.53 5.73±0.94	4.15±0.15 6.84±0.67	3.26±0.52 6.3±0.68	4.41±0.93 7.44±0.82	3.76±0.70 6.7±0.89
T2	2.25±0.57 5.38±0.73	2.61±0.54 5.19±0.94	3.27±0.49 5.82±0.90	2.81±0.51 5.64±0.71	3.52±0.77 6.26±1.09	3.09±0.65 5.64±0.90
T3	2.07±0.38 4.53±0.63	2.14±0.41 4.40±0.81	2.70±0.60 4.93±0.83	2.28±0.36 4.64±0.65	2.98±0.73 5.11±1.24	2.50±0.47 4.60±0.81
T4	1.76±0.42 3.89±0.63	1.55±0.28 3.67±0.84	1.97±0.43 4.10±0.74	1.94±0.35 4.09±0.51	2.25±0.66 4.36±0.91	2.06±0.53 3.93±0.88
T5	1.66±0.42 3.85±0.56	1.65±0.27 3.59±0.64	2.20±0.49 3.97±1.00	1.90±0.31 3.91±0.46	2.29±0.50 4.39±0.84	2.13±0.43 4.13±0.82
T6	1.81±0.37 3.99±0.54	1.73±0.27 3.76±0.68	2.24±0.68 4.27±1.05	1.91±0.39 3.92±0.55	2.42±0.55 4.56±0.93	2.26±0.50 4.16±0.81
T7	1.99±0.43 4.19±0.59	1.86±0.57 3.84±0.61	2.45±0.69 4.43±1.02	1.96±0.35 3.96±0.47	2.58±0.64 4.81±0.99	2.39±0.49 4.25±0.82
T8	2.26±0.54 4.54±0.64	1.98±0.35 4.06±0.67	2.71±0.66 4.78±0.88	2.38±0.53 4.54±0.57	3.16±1.50 5.09±1.08	2.64±0.51 4.64±1.16
T9	2.60±0.56 4.84±0.74	2.14±0.36 4.50±0.58	2.93±0.62 5.04±0.73	2.53±0.62 4.72±0.67	3.30±0.90 5.70±1.04	2.84±0.62 5.01±0.79
T10	2.86±0.71 5.34±0.94	2.42±0.49 4.83±0.72	3.31±0.65 5.75±0.95	2.99±0.64 5.31±0.83	3.98±0.98 6.42±1.41	3.39±0.97 5.85±1.18
T11	3.21±0.65 5.83±0.93	2.89±0.63 5.49±0.66	3.81±0.78 6.36±1.09	3.42±0.80 6.03±0.99	4.65±1.00 7.22±1.44	4.13±1.28 6.57±1.38
T12	3.51±0.69 6.27±1.11	3.22±0.69 6.00±0.95	4.31±0.75 6.69±1.13	3.73±0.85 6.52±1.13	4.99±1.05 7.83±1.58	4.63±1.32 7.39±1.64

pedicle isthmus width was always greater than the transverse pedicle isthmus width except at T1. There were no significant differences between male and female patients at each level ($p>0.05$). The factor of age appeared to present an associative effect along aspects of transverse width (r_s range: M group 0.474~0.809, F group 0.416~0.556, $p<0.05$).

The length of the pedicle from the posterior cortex to the anterior cortex of the vertebra

The longest diameter was at T12. The diameters showed an increasing dimension from T1 to T12 at almost every level (Table 3): 5- to 8-year-olds 28.11~32.26 mm (M),

Table 2 Sagittal diameter (mm)

	5–8 years		9–11 years		12–14 years	
	M	F	M	F	M	F
T1	3.40±0.52	3.43±0.62	3.84±0.44	4.04±0.41	4.14±0.54	4.12±0.79
T2	3.56±0.58	3.64±0.76	4.14±0.38	4.32±0.44	4.43±0.58	4.45±0.86
T3	3.97±0.74	4.07±0.83	4.49±0.63	4.52±0.61	4.79±0.71	4.93±0.88
T4	4.23±0.63	4.38±0.80	5.14±0.89	4.75±0.55	5.27±0.87	5.34±0.78
T5	4.66±0.70	4.64±0.89	5.66±1.00	5.23±0.83	5.82±0.82	5.73±1.08
T6	4.93±0.81	5.16±0.91	6.04±0.94	5.72±0.79	6.43±1.02	6.43±1.00
T7	5.66±0.93	5.67±1.02	7.03±0.86	6.49±0.98	6.92±1.01	7.21±1.16
T8	6.13±1.00	6.36±0.87	7.43±1.07	7.10±0.67	7.91±1.10	7.71±0.96
T9	6.91±1.03	7.11±0.84	7.98±1.10	7.58±0.87	8.77±1.25	8.53±1.28
T10	7.64±1.03	7.90±0.86	8.76±0.96	8.46±0.97	10.02±1.13	9.43±1.55
T11	8.34±1.00	8.63±1.06	9.73±1.09	9.47±1.10	11.21±1.04	10.59±1.79
T12	9.39±1.36	9.46±1.32	10.51±1.18	10.36±1.12	12.35±1.28	11.67±1.67

Table 3 The length of the pedicle from the posterior cortex to the anterior cortex of the vertebra (mm)

	5–8 years		9–11 years		12–14 years	
	M	F	M	F	M	F
T1	28.57±2.18	27.28±1.86	29.99±3.71	29.06±1.43	31.94±3.10	31.03±2.61
T2	28.11±2.46	27.79±2.49	30.33±2.44	29.20±1.63	32.46±3.70	30.89±2.43
T3	28.43±2.46	28.95±2.45	31.81±4.32	29.31±2.31	33.17±3.06	31.79±2.93
T4	29.75±2.90	29.04±2.05	32.28±3.53	30.17±1.63	34.10±2.94	31.97±2.15
T5	28.91±1.98	29.41±2.25	31.53±3.81	30.86±2.60	34.64±2.61	32.37±2.98
T6	29.75±2.38	29.34±1.69	32.83±3.18	31.86±3.19	34.61±2.96	33.35±3.53
T7	30.15±3.15	30.17±2.39	33.64±3.51	32.40±2.99	35.79±3.78	33.99±3.32
T8	30.15±2.82	30.81±2.53	34.21±3.49	31.98±2.55	37.86±3.58	34.55±3.66
T9	31.37±3.08	31.36±2.49	35.02±3.64	33.54±3.15	37.97±4.40	35.36±3.07
T10	32.37±3.13	31.83±2.80	35.44±3.53	33.69±2.49	39.22±4.04	34.70±4.71
T11	32.07±2.80	31.78±3.20	34.95±4.87	33.24±3.20	38.08±3.55	36.22±4.75
T12	32.26±2.89	32.29±3.62	34.91±5.27	34.01±3.58	39.42±4.12	37.71±5.65

27.28~32.29 mm (F); 9- to 11-year-olds 29.99~34.91 mm (M), 29.06~34.01 mm (F); 12- to 14-year-olds 31.94~39.42 mm (M), 31.03~37.71 mm (F). The factor of age appeared to present an associative effect along aspects of transverse width (r_s range: M group 0.456~0.659, F group 0.327~0.613, $p<0.05$). There was a significant difference between male and female patients at each level ($p>0.05$).

Transverse pedicle angle

There was a significant difference between male and female patients at each level ($p>0.05$) (Table 4). The angles were widest at T1 with gradual reduction caudally. The angles were negative at T11 and T12. The variable of age had no associative effect on transverse pedicle angles measured (r_s range: M group -0.06~0.337, F group -0.082~0.482, $p<0.05$).

The variable of gender had no associative effect on the thoracolumbar vertebral dimensions measured (r_s range:

0.06~0.14). The factor of age appeared to present an associative effect along aspects of sagittal width and distance to the anterior cortex (r_s range: 0.46~0.52). Vertebral level appears to be the soundest predictor of thoracolumbar size dimensions and the explanation of variance throughout most dimensions examined (r_s range: 0.51~0.76).

Measurements were repeatedly made by two investigators. The coefficient of correlation (r_s) was 0.977 ($p<0.001$). There was no significant difference between the two investigators, so the results were highly credible.

Discussion

Spinal instrumentation systems that use pedicle screws for posterior stabilisation have gained popularity in recent years. Transpedicular fixation offers a sound biomechanical instrumentation to manage various pathological conditions of the spine. A discrepancy between pedicle width and

Table 4 Transverse pedicle angle

	5–8 years		9–11 years		12–14 years	
	M	F	M	F	M	F
T1	30.94±5.25	29.42±5.77	30.83±4.55	31.16±3.71	30.69±4.59	31.40±3.92
T2	20.14±4.38	20.89±5.79	21.73±5.76	23.17±4.11	20.19±4.02	18.76±6.22
T3	13.56±3.15	13.72±5.73	13.44±5.18	15.45±6.62	13.17±4.30	12.57±4.57
T4	9.55±2.84	11.09±5.17	9.27±3.95	8.23±4.38	7.41±3.45	7.57±3.11
T5	8.23±2.86	8.82±3.81	8.24±3.81	8.24±3.67	6.46±2.99	6.30±3.45
T6	7.68±2.83	8.21±2.31	6.60±4.36	6.01±3.50	5.14±3.32	5.23±1.95
T7	6.68±2.47	7.29±2.71	5.86±2.97	5.71±3.27	4.72±2.38	4.42±2.05
T8	5.90±2.25	7.13±2.89	5.69±2.52	4.21±2.90	4.41±2.91	3.68±1.75
T9	5.93±1.70	6.81±2.25	5.28±2.68	5.23±3.61	4.24±2.91	4.02±2.07
T10	6.10±2.33	6.45±3.35	5.07±2.72	6.06±4.01	3.94±2.93	4.77±3.09
T11	-5.34±2.93	-6.37±1.84	-5.60±4.14	-3.95±2.49	-3.80±3.00	-4.72±2.21
T12	-5.01±2.78	-5.54±4.42	-4.78±3.01	-4.31±2.98	-4.48±3.00	-4.26±2.93

screw diameter can lead to expansion or fracture of the pedicle wall and cut-out of the screw thread [6]. Therefore, the success of the technique depends largely on the best knowledge of pedicle morphology.

Pedicle screw instrumentation to treat several spinal disorders provides advantages in the adult spine. Pedicle screw instrumentation provides additional advantages in the paediatric spine. The ability to control three columns can help to eliminate the necessity for anterior surgery and decrease the risk of the crankshaft phenomenon in this population [5]. The rigid fixation provided enables the surgeon to limit the number of fused levels, which helps to protect the growth potential of a growing spine [9]. Despite these advantages, it has rather limited use in paediatric populations because of the risk of iatrogenic spinal stenosis and mainly because of the disproportionate sizes of the pedicles in this population and the commercially available screws [1]. The fact that there were no healthy modern children is a limitation of this study.

Pedicle screw technology has been more and more applied to children with spinal disorders. This is particularly true for children in a period of growth and development. The immature vertebra requires a complete understanding of the pedicle morphology, as well as the development and growth of the vertebra. Porter et al. reported that the median sagittal diameter and the spinal canal for four-year-old children has matured. Rekate et al. [7] have concluded that the posterior pedicle fixation system can be applied to children over the age of four. They considered that pedicle screws applied to this age of patient was a safe and effective option. The survey found that the transverse diameter (r_s : M group 0.387~0.594, F group 0.335~0.513, $p<0.05$), height (r_s : M group 0.474~0.809, F group 0.416~0.556, $p<0.05$) and pedicle length (r_s : M group 0.456~0.659, F group 0.327~0.613, $p<0.05$) are significantly relevant to age. They increase with age. The cross-sectional angle (r_s : M group $-0.06\sim0.337$, F group $-0.082\sim0.482$, $p>0.05$) is not significantly relevant to age. No significant changes were found in the cross-sectional angle with age. Therefore, the choice of pedicle screw diameter and length used in children should be determined according to their age group. No difference was found between sexes.

The pedicle of children, compared with the adult pedicle, shows that it is not yet fully mature. A child's pedicle is proportionately smaller than in the adult spine [8]. Within the diameter of all ages, height is less than adults. This study found that pedicle morphology in the child and the adult follows similar trends. In general, compared with the average adult data, young spines demonstrated near uniform reduction in the linear pedicle dimensions at each vertebral level. Compared with the study by Zindrick et al. [12] our measurements were significantly smaller at most

levels. The difference in pedicle size compared with whites could be attributed to the overall shorter body stature of Asians. The paediatric patients promise higher dilation potential considering the elasticity of their bones. Although some surgeons may believe in the "in-out-in" technique, our view is that screws that fit within the pedicle are the safest. Various authors have documented that the cross section of the pedicles is oval; hence, the sagittal pedicle isthmus width is always greater than the transverse pedicle isthmus width, which is the limiting factor in choosing the diameter of the pedicle screws.

The angular dimensions showed little change due to vertebral growth. The increasing distance to the anterior cortex seen with increasing age is primarily the result of vertebral body growth. When using pedicle screws in the immature spine, safe screw length would be expected to be less than that used in the adult vertebra. The depth of penetration should be 50–80% of the AP distance, without any attempt being made to engage the anterior cortex [3, 13].

However, the values obtained were less than those obtained in other series, which is not surprising, because the build of an average Chinese child is noticeably less than that of an average white person.

Care should be taken to accurately ascertain pedicle size before surgery so that improper use of screws can be avoided. Preoperative CT evaluation would therefore be recommended for prospective candidates of thoracic pedicle instrumentation.

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