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ORIGINAL ARTICLE

Pedicle morphology of the thoracic spine in preadolescent idiopathic scoliosis: magnetic resonance supported analysis

Hüseyin Çatan · Levent Buluç · Yonca Anık · Erhan Ayyıldız · Ahmet Yılmaz Şarlak

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Abstract Although several studies have been reported on the adult vertebral pedicle morphology, little is known about immature thoracic pedicles in patients with idiopathic scoliosis. A total of 310 pedicles (155 vertebrae) from T1 to T12 in 10–14 years age group were analyzed with the use of magnetic resonance imaging and digital measurement program in 13 patients with right-sided thoracic idiopathic scoliosis. Each pedicle was measured in the axial and sagittal planes including transverse and sagittal pedicle width and angles, chord length, interpedicular distance and epidural space width on convex and concave sides of the curve. The smallest transverse pedicle widths were in the periapical region and the largest were in the caudal region. No statistically significant difference in transverse pedicle widths was detected between the convex and concave sides. The transverse pedicle angle measured 15.56° at T1 and decreased to 6.32° at T12. Chord length increased gradually from the cephalad part of the thoracic spine to the caudad part as the shortest length was seen at T1 convex level with a mean of 30.45 mm and the largest length was seen at T12 concave level with a mean of 41.73 mm. The width of epidural space on the concave side was significantly smaller than that on the convex side in most levels of the curve. Based on the anatomic measurements, it may be reasonable to consider thoracic pedicle screws in preadolescent idiopathic scoliosis.

Keywords Thoracic pedicle morphology · Preadolescent idiopathic scoliosis · Immature (pediatric) spine · Pedicle screw · Magnetic resonance imaging

H. Çatan
Department of Orthopaedics and Traumatology, Adıyaman State Hospital, Adıyaman, Turkey

L. Buluç · E. Ayyıldız · A. Y. Şarlak (✉)
School of Medicine, Department of Orthopaedics and Traumatology, Kocaeli University, Umuttepe, 41380 Kocaeli, Turkey
e-mail: kouortopcom@yahoo.com

Y. Anık
School of Medicine, Department of Radiology, Kocaeli University, Kocaeli, Turkey

Introduction

Pedicle screw instrumentation systems have become the most popular method in all types of adolescent scoliosis with well accepted advantages in terms of curve correction and less correction loss [2, 6, 9, 14, 15].

They are not preferred as often, however, in the thoracic curves of juvenile-preadolescent group. This may be because of the more commonly preferred conservative means and also the nonfamiliar thoracic pedicle morphology at the younger age group [1, 5, 17]. Although several studies have been reported on the pedicle morphology of the adult thoracolumbar spine [4, 16, 20], only a few number of studies analyzed the thoracic pedicle morphology in immature spines [5, 19]. The data from these reports mostly depend on the investigations of normal spines. However, a recent study by Liljenqvist et al. [8] showed significant intravertebral deformity and asymmetrical growth of the vertebrae in scoliotic spines.

The purpose of this study is to analyze the thoracic pedicle morphology in preadolescent patients with idiopathic scoliosis using magnetic resonance imaging for efficient screw length–diameter and optimal angle of insertion.

Materials and methods

Thirteen patients with right-sided thoracic idiopathic scoliosis were included in the study. Four curves were classified as type I, four as type II, and five as type III, according to the system King et al [7].

A total of 155 vertebrae (310 pedicles) were investigated. The most frequent end-vertebrae of the thoracic curves were the T4 and the T12 thoracic vertebrae.

The average Cobb angle was 48.7° (range: 30°–80°) for the thoracic curve. Ten female and three male patients with an average age of 13.1 years (range: 10–14) were examined.

Magnetic resonance imaging examinations were performed with a 1.5 T MR scanner (Philips Gyroscan Intera Master, Eindhoven, Netherlands), 30 mT/m maximum gradient strength, and 150 mT/m/ms slew rate using a synergy spine coil. The patients were placed in the supine position. Sagittal and axial T1 and T2 weighted images were obtained in which acquisition volumes were adapted to the individual spinal curvature. A saturation pulse with a thickness of 100 mm was used to reduce respiration and motion artifacts. The imaging parameters for turbo spin echo T2 weighted imaging were TR/TE: 3,500/120; matrix: 304×512; scan duration: 2 min 58 s and for T1 weighted imaging TR/TE: 400/11; matrix: 288×512; scan duration: 3 min, with a slice thickness: 4 mm and gap: 1 mm.

The axial and sagittal images of the corresponding vertebrae were calculated using a digital measurement program (Canvas 9.0) allowing digital measurements of distances and angles with a precision of 0.1 mm and 0.1°, respectively.

The measurements in the transverse plane included chord length, transverse pedicle width, transverse pedicle angle, interpedicular spinal canal diameter, and the width of the epidural space on the concave and convex sides of the curve (Fig. 1, 2). The measurements in the sagittal plane included sagittal pedicle width and sagittal pedicle angle (Fig. 3). All the measurements were performed according to the descriptions presented in the studies by Vaccaro and Zindrick [16, 20].

The chord length was measured as the distance from the posterior cortical entry point of the pedicle to the anterior vertebral cortex in line with the axis of the pedicle. The transverse pedicle width was measured as

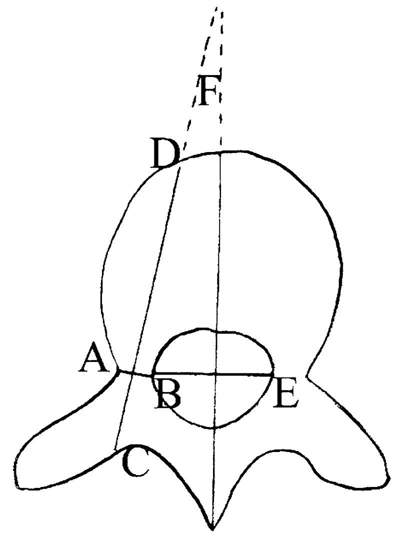

Fig. 1 Transaxial illustration of a thoracic vertebra, showing the chord length (*CD*), the transverse pedicle width (*AB*), the transverse pedicle angle (*F*), and the interpedicular distance (*BE*)

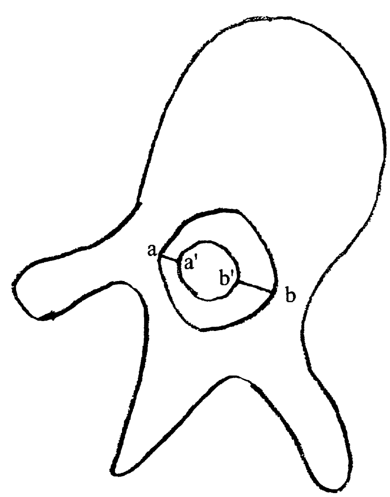

Fig. 2 Illustration of a thoracic vertebra with the measurements of epidural space on the concave (*aa′*) and convex (*bb′*) sides of the curve

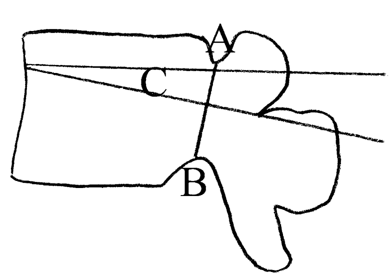

Fig. 3 Sagittal illustration of a thoracic vertebra demonstrating the sagittal pedicle width (*AB*) and the sagittal pedicle angle (*C*)

the medial–lateral outer cortical diameter at the narrowest part of the pedicle. The transverse pedicle angle was measured as the angle between a line perpendicular to the transverse isthmus and a sagittal midvertebral line. The interpedicular distance was measured as the distance between the medial walls of the corresponding pedicles. The sagittal pedicle width was measured as the superior–inferior outer cortical height of the pedicle. The sagittal pedicle angle was measured between a line perpendicular to the sagittal isthmus and the posterior vertebral body in the sagittal plane.

All data were collected and analyzed using SPSS version 13.0 (SPSS Inc., Chicago, IL). The parameters on the concave and convex side of each curve were separately analyzed. Statistically significant differences to compare the parameters were tested for using a Wilcoxon matched-pairs signed-rank test. Significance was established at the $P < 0.05$ level

Results

Transverse plane measurements

Pedicle width

The outer cortical diameter at the narrowest part of the pedicle was measured (Table 1).

The widest pedicle width was seen at T12 convex level with a mean value of 5.90 mm. In the upper and middle thoracic spine the widest pedicle was seen at T1 concave level with a mean of 5.06 mm. The narrowest pedicles were at the periapical regions at T5, T6, and T7 concave levels with mean values of 4.32, 4.26, and 4.31 mm, respectively. Except for the T1 concave, T11 and T12 levels, all pedicles were measured with a mean width of less than 5 mm.

Though the mean dimensions for the concave–convex pedicle in the corresponding levels were similar, a large variation was noted when each level was examined. No statistically significant difference in pedicle widths was detected between the convex and concave sides of the curve except T11 level.

Pedicle angle

The mean transverse pedicle angle was 15.56° at T1 and 6.32° at T12 (Table 1). In the transverse plane, there was an insignificant decrease of the pedicle angle toward the thoracolumbar spine. In the apical region of the thoracic spine, mean thoracic pedicle angles for the corresponding concave and convex levels were similar.

Chord length

Chord length is described as the maximum length that a screw can be inserted into each pedicle. Chord length increased gradually from the cephalad aspect of the thoracic spine to the caudad (Table 1). The shortest chord length was seen at T1 convex level with a mean of 30.45 mm. The largest chord length was seen at T12 concave level with a mean of 41.73 mm. At the apical region of the thoracic curve no significant difference in chord length was detected between the concave and convex sides of the curve except T9 level.

Epidural space width and interpedicular distance

Epidural space of at least 4.68 mm was detected on all convex levels (Table 1). It was ≤2.25 mm at the apical concave segments (T7–T9). The width of the epidural space on the concave side was significantly smaller than that on the convex side at all levels except T2, T4, T5, and T12 ($P < 0.05$). Interpedicular distance was larger than 20 mm in all levels except T5, T6, T7, T8, and T9 (Table 2).

Sagittal plane measurements

Pedicle width

The sagittal width showed a decrease through the thoracic spine from caudad to cephalad direction with the minimum at T1. The widest sagittal pedicle width was seen at T11 convex level with a mean value of 10.50 mm. The narrowest sagittal width was seen at T1 convex level with a mean value of 6.46 mm. Except for T1 and T2 levels, all the thoracic sagittal pedicle widths were greater than 7 mm (Table 3).

Pedicle angle

The thoracic pedicles were inclined in a cephalad direction from posterior to anterior in sagittal plane in all of the patients. The largest angulation was measured at T2 convex level with a mean value of 15.92° (12.00–19.00) (Table 3). No statistically significant difference was detected between the convex and concave sides of the curve.

Discussion

Vertebral morphology in idiopathic scoliosis has been suggested to be substantially different [3, 8, 12]. These

Table 1 Morphometric measurements in the transverse plane

Level	Pedicle width (mm)			Pedicle angle (°)			Chord length (mm)			Epidural distance (mm)		
	Convex	Concave	*P* value*	Convex	Concave	*P* value*	Convex	Concave	*P* value*	Convex	Concave	*P* value*
T1	4.84 ± 1.19 (3.20–7.00)	5.06 ± 1.51 (3.30–8.00)	0.593	14.58 ± 6.11 (6.00–26.80)	16.55 ± 7.66 (6.92–32.12)	0.328	30.45 ± 6.19 (19.20–46.00)	30.96 ± 5.09 (24.00–45.00)	0.61	5.76 ± 1.66 (3.00–9.20)	3.98 ± 2.39 (1.20–8.20)	**0.021**
T2	4.88 ± 1.36 (3.20–7.40)	4.70 ± 1.31 (2.90–7.00)	0.579	11.18 ± 5.92 (−1.28–20.13)	12.68 ± 6.86 (−0.53–22.03)	0.195	32.06 ± 4.94 (26.50–46.00)	32.35 ± 5.0 4 (24.80–45.00)	0.906	5.15 ± 1.96 (3.30–9.40)	3.83 ± 2.32 (0.80–7.60)	0.136
T3	4.41 ± 1.19 (3.30–8.00)	4.39 ± 0.90 (3.20–6.00)	0.636	12.34 ± 5.81 (3.72–21.03)	12.88 ± 5.71 (5.93–26.07)	0.695	33.92 ± 4.37 (29.10–46.00)	34.36 ± 4.76 (28.00–44.00)	0.754	5.12 ± 1.66 (2.50–8.20)	2.96 ± 1.61 (0.50–5.50)	**0.01**
T4	4.50 ± 1.07 (3.30–7.00)	4.46 ± 1.05 (3.10–6.00)	0.905	10.71 ± 3.83 (6.00–17.88)	11.88 ± 4.34 (7.00–20.47)	0.221	35.12 ± 5.30 (28.30–47.00)	34.37 ± 4.97 (27.70–44.00)	0.195	4.68 ± 1.96 (1.80–7.10)	3.63 ± 2.80 (0.80–9.40)	0.221
T5	4.46 ± 1.43 (2.70–8.00)	4.32 ± 1.12 (2.80–6.00)	0.61	10.54 ± 4.15 (4.85–19.03)	10.77 ± 4.03 (5.87–18.00)	0.701	36.23 ± 5.68 (26.60–45.00)	36.30 ± 5.61 (29.80–46.00)	0.701	4.80 ± 2.08 (0.80–8.30)	3.06 ± 2.31 (0.80–7.80)	0.108
T6	4.60 ± 1.67 (2.90–9.00)	4.26 ± 1.10 (2.80–6.00)	0.202	9.20 ± 3.02 (4.28–13.80)	10.79 ± 4.23 (5.00–19.30)	0.133	37.36 ± 3.10 (32.80–43.00)	37.10 ± 3.95 (31.80–45.00)	0.724	5.24 ± 2.15 (2.40–9.40)	2.63 ± 1.62 (1.00–5.80)	**0.006**
T7	4.73 ± 1.21 (3.20–7.00)	4.31 ± 1.16 (2.70–6.60)	0.139	9.46 ± 4.18 (2.12–15.33)	9.66 ± 3.56 (4.00–15.97)	0.754	36.96 ± 4.54 (29.60–46.00)	38.3 ± 3.47 (31.30–44.00)	0.238	5.55 ± 2.77 (1.90–9.70)	2.06 ± 1.06 (0.40–3.80)	**0.04**
T8	4.72 ± 1.23 (3.00–7.50)	4.36 ± 0.95 (3.30–6.20)	0.184	9.31 ± 4.37 (3.00–16.63)	8.31 ± 5.14 (−1.58–15.07)	0.239	38.72 ± 4.29 (31.50–45.40)	39.71 ± 4.04 (32.60–46.00)	0.059	5.76 ± 2.98 (2.50–10.60)	1.94 ± 0.73 (0.40–3.00)	**0.002**
T9	4.79 ± 1.09 (3.70–7.60)	5.05 ± 0.61 (4.10–6.20)	0.201	7.78 ± 4.24 (2.15–15.43)	8.75 ± 5.15 (−1.53–17.52)	0.31	37.53 ± 4.84 (28.70–46.00)	38.83 ± 4.41 (32.90–47.00)	**0.031**	5.45 ± 2.70 (2.00–9.90)	2.25 ± 1.31 (0.50–5.50)	**0.005**
T10	4.94 ± 1.12 (3.50–7.60)	4.97 ± 1.41 (3.40–8.60)	0.645	7.88 ± 5.03 (−0.37–15.35)	7.67 ± 5.53 (−1.03–16.57)	0.754	39.74 ± 4.89 (30.10–48.00)	39.80 ± 5.55 (30.70–51.60)	0.507	4.75 ± 1.94 (2.50–8.50)	2.75 ± 1.99 (0.50–7.60)	**0.025**
T11	5.67 ± 1.71 (3.50–9.20)	5.16 ± 1.32 (3.50–7.70)	**0.012**	6.05 ± 5.28 (−4.10–14.47)	6.24 ± 5.44 (−4.88–15.62)	0.308	39.35 ± 5.89 (30.10–49.00)	40.26 ± 4.93 (33.20–49.40)	0.167	4.76 ± 2.66 (2.00–11.40)	3.06 ± 1.88 (1.40–7.60)	**0.025**
T12	5.90 ± 1.80 (3.50–10.00)	5.73 ± 1.71 (3.40–10.00)	0.477	6.49 ± 6.28 (−5.75–16.38)	6.16 ± 7.26 (−3.90–22.28)	0.656	41.23 ± 7.39 (32.70–58.00)	41.73 ± 7.80 (32.80–58.00)	0.313	5.41 ± 3.57 (1.00–11.70)	3.29 ± 1.59 (0.70–5.30)	0.075

The values are given as the mean and the standart deviation, with the range in parentheses

*Significant values ($P < 0.05$) are marked with bold font

Table 2 Interpedicular distance

Level	Interpedicular distance (mm)
T1	21.80 ± 2.27 (16.40–24.10)
T2	20.80 ± 2.46 (16.50–25.00)
T3	20.51 ± 2.86 (15.30–25.00)
T4	20.57 ± 2.55 (14.40–24.00)
T5	19.36 ± 2.55 (15.50–24.00)
T6	19.73 ± 2.66 (16.40–25.00)
T7	19.44 ± 2.74 (16.30–25.00)
T8	19.90 ± 2.77 (15.70–25.00)
T9	19.96 ± 2.88 (16.90–25.00)
T10	20.79 ± 3.22 (16.10–26.60)
T11	20.92 ± 3.76 (15.60–27.10)
T12	22.27 ± 3.54 (16.90–28.00)

The values are given as the mean and the standard deviation, with the range in parentheses

morphologic study results together with the problem of standardization in measurement techniques have raised justifiable concerns regarding thoracic pedicle screw usage in immature spinal deformities.

It was shown that a vertebral tilt of even ≥10° in the frontal plane influences the accuracy of measurements in scoliotic vertebra [18].

Computed axial tomography (CT) allows an alignment of the gantry only in the sagittal plane which may impair the accuracy of measurements [10, 11]. While CT scanning of all levels would be the ideal technique, the impracticability of such study is self evident. Magnetic resonance imaging (MRI), on the other hand, has the disadvantage of less clear depiction of cortical structures [8].

In the measurement of critical pedicle width, Liljenqvist et al. [8] measured endosteal pedicle width that would correlate with the cancellous canal of the pedicle. O'Brien suggested measuring the outside pedicle dimension by taking plastic deformation into account. It was suggested that in only later adolescent and teen years, the wider pediculed thoracolumbar spine may become large enough to safely accept pedicle screws [11, 13].

Our measurements of the endosteal pedicle width in the 10–14 year group were consistently larger than the measurements of pedicle widths that have been reported in previous studies on both the morphology of normal and scoliotic spines [8, 19]. We think that in T1–T2 levels, 4 mm screws can be used; in T3–T9 levels 3.5 mm screws can be introduced where T9–T12 levels may well accept 4.5 mm screws in preadolescent idiopathic scoliosis.

Our findings in the less critical sagittal plane are in accordance with the recently published pediatric data. Throughout most of the thoracic spine, the pedicle inclines in a cephalad direction from posterior to anterior.

The distance of the anterior cortex is important in preventing anterior cortex perforation and possible injury to vital structures [16, 17]. Regarding the findings in the chord length which may have some change due to entrance point, 25 mm screws in T1–T2, 30 mm screws between T3 and T7 and 35 mm screws between T7 and T12 may be suggested.

Our results concerning the transverse angulation follow the trends similar to previous studies [4, 16, 20]. Angular dimensions have been shown not to change due to vertebral growth [19, 20]. There is an insignificant decrease of pedicle angle toward the thoracolumbar spine.

Previous studies reported a variation of the transverse pedicle widths between the concave and convex sides [8, 11]. In the current study, comparing the

Table 3 Morphometric measurements in the sagittal plane

Level	Pedicle width (mm)			Pedicle angle (°)		
	Convex	Concave	*P* value*	Convex	Concave	*P* value*
T1	6.46 ± 1.34 (5.00–10.00)	6.49 ± 1.04 (4.50–8.00)	0.865	14.44 ± 2.13 (10.00–17.00)	14.45 ± 2.55 (10.00–18.00)	0.713
T2	6.94 ± 1.16 (5.20–9.00)	6.71 ± 1.03 (5.20–8.50)	0.102	15.92 ± 2.07 (12.00–19.00)	15.50 ± 2.60 (10.00–18.00)	0.115
T3	7.20 ± 0.75 (6.40–9.00)	7.11 ± 0.83 (5.50–8.40)	0.671	15.54 ± 2.54 (11.00–18.80)	15.54 ± 2.72 (10.00–18.80)	0.498
T4	7.34 ± 0.60 (6.40–8.40)	7.24 ± 0.82 (5.60–8.40)	0.518	14.67 ± 3.02 (10.00–17.90)	14.44 ± 3.18 (9.00–17.80)	0.088
T5	7.70 ± 0.73 (5.60–8.50)	7.37 ± 1.02 (5.00–8.50)	0.233	13.68 ± 2.44 (10.00–17.00)	13.66 ± 2.60 (9.00–17.00)	0.715
T6	8.13 ± 1.34 (4.00–9.00)	7.97 ± 1.32 (4.80–10.00)	0.553	12.36 ± 2.44 (8.00–16.00)	12.21 ± 2.29 (8.00–15.60)	0.765
T7	8.43 ± 1.43 (4.00–10.00)	8.47 ± 1.48 (4.80–10.00)	0.397	10.83 ± 2.40 (7.00–15.00)	10.46 ± 2.63 (6.00–15.00)	0.105
T8	8.69 ± 0.66 (7.70–10.00)	8.82 ± 1.19 (5.50–10.00)	0.345	9.94 ± 2.00 (6.00–12.60)	9.58 ± 2.36 (5.00–12.50)	0.157
T9	9.46 ± 0.63 (8.80–11.00)	9.14 ± 1.35 (5.00–10.20)	0.622	11.08 ± 1.59 (8.00–14.00)	10.87 ± 1.72 (8.00–14.00)	0.216
T10	10.20 ± 1.08 (8.80–12.00)	9.95 ± 1.86 (5.00–12.00)	0.799	11.69 ± 2.02 (9.00–15.50)	11.69 ± 2.02 (9.00–15.50)	1
T11	10.50 ± 1.27 (8.80–13.00)	9.74 ± 1.61 (5.50–12.00)	**0.018**	11.76 ± 2.31 (8.00–16.50)	11.53 ± 2.81 (5.00–16.50)	0.285
T12	10.51 ± 1.39 (7.70–12.00)	9.81 ± 1.88 (6.50–12.00)	0.115	12.35 ± 2.85 (8.00–16.40)	12.21 ± 2.98 (8.00–16.40)	0.336

The values are given as the mean and the standard deviation, with the range in parentheses

*Significant values ($P < 0.05$) are marked with bold font convex and concave sides with respect to pedicle width, chord length, and transverse angulation no significant difference was detected. Apical segments did not show any variation in morphology to suggest asymmetrical intravertebral deformity. The shift of the dural sac toward concavity, causing a consistently smaller epidural safe zone in apical segments, makes the screw insertion in axial plane more important. In the apical segments a more lateral entry on the concave side might be suggested.

In conclusion, this study indicates that pedicle screws with appropriate size and length can be safely used throughout the thoracic spine in preadolescent idiopathic scoliosis. We agree with O'Brien that the deformity itself, rather than the local vertebral morphology, increases the degree of difficulty in pedicular fixation.

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