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MORPHOLOGICAL ANALYSIS OF THORACOLUMBAR SPINE PEDICLES IN ADOLESCENT IDIOPATHIC SCOLIOSIS

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ABSTRACT

Objective: Adolescent idiopathic scoliosis (AIS) is a three-dimensional spinal deformity, and pedicle morphology can change on the concave and convex sides of the curvature. This study aimed to evaluate the pedicle morphology of the thoracic and lumbar vertebrae in AIS via computed tomography (CT).

Materials and Methods: Patients diagnosed with AIS between 2019 and 2021 were identified by scanning the Picture Archiving and Communication System. Patients with a scoliosis radiograph and a Cobb angle of 40º or more were included in the study. The pedicle length (PL), axial pedicle angle (APA), endosteal pedicle width (EPW), and cord length (CL) were measured from the T1 to L5 vertebrae from the CT sections of the patients. The Cobb angle, apical vertebral translation distance, and vertebral rotations were measured using standing AP and lateral radiographs.

Results: The mean age of the 30 patients was 16.37±3.0 and 93.3% were females. The mean main-thoracic Cobb angle was 47.87º±7.99º. There was a significant, negatively weak relationship between the Cobb angle and T5 and T6 left PL (r=-0.485 and r=-0.371, respectively), a moderately negative relationship between T7 and L3 left PL (r=0.506 and r=-0.508, respectively). There was no significant correlation between the Cobb angle and endosteal pedicle values (p>0.05). While the correlation between the vertebral rotation and the right endosteal pedicle was moderate at T4, a significant but low correlation was found for T3, T5, T6, T7, and T9 (p<0.05).

Conclusion: The EPW was shorter and the CL was longer on the concave side of the vertebrae in the apical region of the AIS deformity. It is essential to know the pedicle morphology order to avoid complications, especially in pedicle screw implantation in the apical concave region.

Keywords: Morphometry, pedicle, scoliosis, thoracic, lumbar

INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is the most common three-dimensional spinal deformity, affecting 2-3% of children between the ages of 10 and 16, and the risk of progression of the curvature is ten times higher in females[1,2]. AIS does not cause an increase in mortality, but if left untreated, the curvature of the spine may progress, leading to abnormal posture, back pain, body image problems, depression, and pulmonary symptoms in large thoracic curves[3]. The exact etiology for AIS is unknown, but it is assumed to be multifactorial with a genetic predisposition[4].

Surgical treatment is generally preferred in patients with a major curvature angle greater than 45°, because curvatures greater than 45° continue to progress even if skeletal maturity is complete[3]. Posterior instrumentation and fusion, which is applied via pedicle screws with a posterior approach, is the most popular method in the treatment of AIS in recent years[5]. In patients diagnosed with AIS, it is very important to determine the morphology of the thoracic and lumbar spine before surgery, because improper placement of pedicle screws can cause serious neurological, vascular or visceral injuries[6-9].

To date, pedicle morphology has been evaluated in many studies on AIS using various measurements and modalities, and asymmetries have been detected at the apex of scoliosis[10-16]. The morphological analysis of vertebrae with two-dimensional radiographs in AIS may be misleading because these radiographs cannot show the true frontal (coronal) or lateral (sagittal) sections of each vertebra[17]. Computed tomography (CT) is widely used to perform a three-dimensional morphological analysis of vertebrae in AIS[18].

The aim of this study was to perform pedicle morphometric measurements and analysis of thoracic and lumbar vertebrae in AIS via CT.

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MATERIALS AND METHODS

The study was approved by the Institutional Review Board of Ankara City Hospital (approval date: 09/22/2021, approval no: E1-21-2026). Informed consent was obtained from all patients to confirm their participation in the study. Patients with AIS were identified by scanning the Picture Archiving and Communication System between 2019 and 2021. Patients who had a scoliosis radiograph, a cobb angle of ≥40°, and were evaluated with CT were included in the study.

The CT imaging technique was used to cut sections from T1 vertebra to L5 vertebrae at 1.5 mm intervals in helical mode (GE Reveluation, Waukesha, WI, USA). The position of the BT Gantry was adjusted parallel to the long axis of the pedicles. The reconstruction was shot at 1250 mm intervals and the pitch ratio was 0.750:1. The acquisition parameters were 130 kVp and 260 mAs. Advantage Workstation AW4.6 (General Electric, Boston, MA, USA) software was used to reformat the transverse view.

The pedicle length (PL), axial pedicle angle (APA), endosteal pedicle width (EPW), and cord length (CL) were measured[19] (Figure 1a, b). The PL was measured as the distance between the transverse line drawn at the anterior border of the vertebral foramen and the entry point of the pedicle posterior cortex. The APA was measured as the angle between the sagittal mid-vertebral line and the line drawn perpendicular to the transverse pedicle isthmus. The EPW was measured as the narrowest distance of the endosteal surface of the pedicle in the axial plane. The CL was measured as the distance from the posterior cortex entry point of the pedicle to the anterior cortex along the transverse axis of the pedicle.

Rotations were measured in the coronal and lateral radiographs taken on a 36-inch cassette while the patient was standing[20] (Figure 2). The Cobb angles and apical vertebral translation distance were measured on the preoperative standing radiography (Figure 3). The AIS classification was made using the Lenke classification. All of the measurements were taken by 2 experienced spine surgeons.

The relationship between the Cobb angles and the PL, APA, EPW and CL values were investigated, as was the relationship between the thoracic and lumbar spine vertebral rotation and the APA and EPW values.

Statistical Analysis

The continuous and categorical variables were summarized as the mean ± standard deviation (after examining the normality) and frequency (percentage), respectively. The Spearman Rho or Pearson correlation coefficients between the measurements was calculated. The critical limits for the correlation coefficients were accepted as <0.30: negligible, <0.50: low, <0.70: moderate, <0.90: high, ≥0.90: very high correlation[21]. The R language[22] packages [DescTools[23] was used to obtain the 95% confidence interval (CI) of the mean, ggplot2[24] was used for drawing the graphs, and correlation[25] was used for correlation analysis] were used with a significance level set at p<0.05.

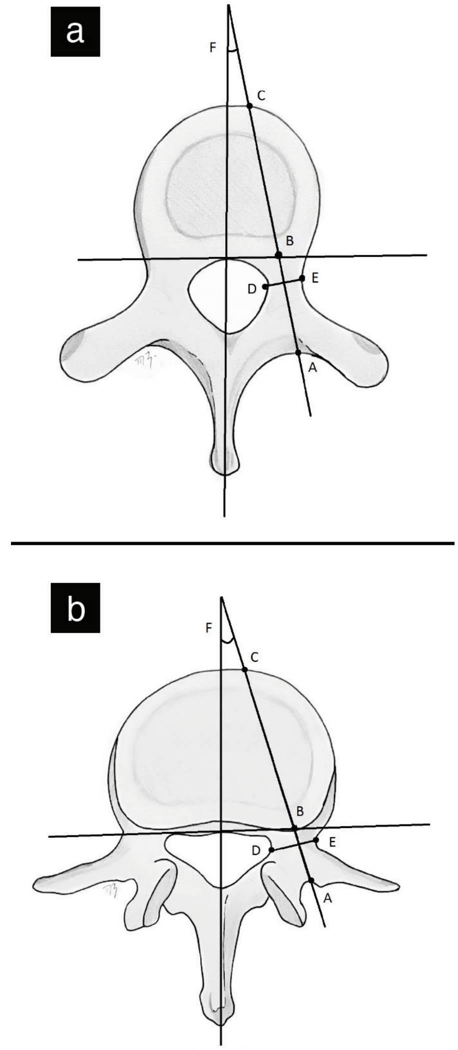

Figure 1. Illustration of pedicle length (AB), endosteal pedicle width (DE), cord length (AC), and axial pedicle angle (F) in the thoracic (a) and lumbar (b) spine

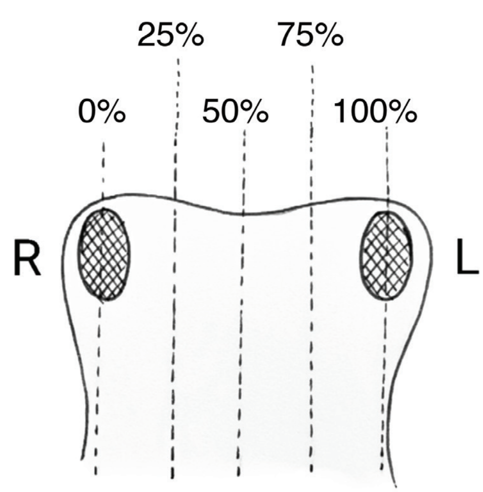

Figure 2. Illustration of the Nash-Moe index used in the grading of vertebral rotation

RESULTS

Of the 30 patients included in the study, 93.3% were female and the mean age was 16.37±3.0 (95% CI: 15.25-17.49, median: 16) years. The mean main-thoracic cobb angle was 47.87°±7.99° (95% CI: 44.89-50.85, median: 46.61°). Other descriptive information about the patients is summarized in Table 1.

The mean and 95% CI of the thoracic and lumbar spine right and left PL, APA, EPW, and CL values are given in Figure 4. The mean T1 left PL was 15.88±1.05 mm, the mean APA was 20.43±3.97°, the mean EPW was 5.49±0.69 mm, and the mean CL was 29.15±2.44 mm (Table 2).

The instrumentation rates of the thoracic and lumbar spines and the percentages of vertebral rotation are presented in Table 3. Especially in the apical region of the curve, the instrumentation

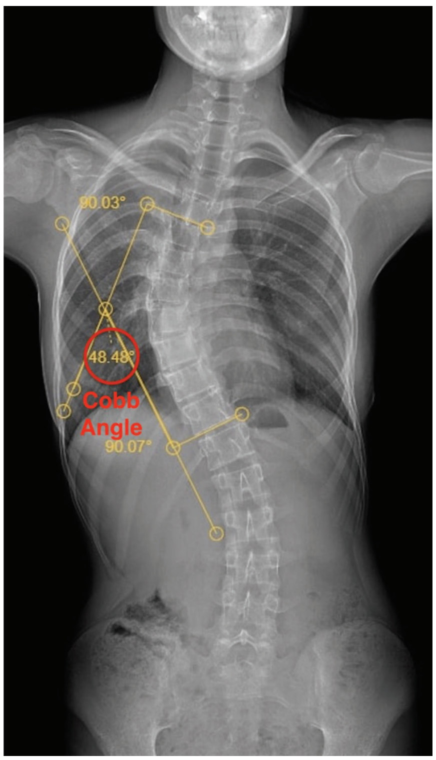

Figure 3. Cobb angle measurement on standing anteroposterior radiograph

percentage of the convex side is much higher than the concave side. It is also seen that the vertebral rotation shifts towards the convex side in the apical regions of both the thoracic and lumbar curvatures.

The relationship between the Cobb angles of the patients and the PL, APA, EPW, and CL values from the T1 to L5 spine were examined (Table 4). Accordingly, between the Cobb angle and T5-T6 left PL, it is low in the negative direction (r=-0.485 and r=-0.371, respectively), and between T7-L3 left PL in the negative direction is moderate significant relationship was determined (p<0.05, r=-0.506 and r=-0.508, respectively). There was no significant correlation between the Cobb angle and endosteal pedicle values (p>0.05).

The relationship between thoracic and lumbar spine vertebral rotation and APA, EPW values was examined and the correlation coefficients obtained are given in Table 5. There was a low positive correlation between the T4 and L2 right APA measurements and the vertebral rotation (p<0.05). While the correlation between the vertebral rotation and the right endosteal pedicle was moderate at T4, a significant but low correlation was found for T3, T5, T6, T7, and T9 (p<0.05). Only the correlation between L3 spine measurements between left APA and EPW was statistically significant and moderately negative (p<0.05). There was no significant correlation between the right APA and EPW values (p>0.05).

DISCUSSION

In recent years, pedicle screw instrumentation has been a common and accepted treatment for patients with AIS. One of the components accompanying the deformity in AIS is the deformity seen in the vertebral pedicles. This deformity may lead to complications in pedicle screw instrumentation. For this reason, awareness of the specific pedicle structure of AIS can prevent complications.

AIS is the most common three-dimensional spinal deformity, affecting 2-3% of children aged 10-16 years, and it has a 10-fold higher risk of progression in females[1,2]. Approximately 93.3% of the patients included in this study were females, and female gender can be shown as a risk factor for AIS. In a study conducted by Guzek et al.[26] on AIS patients, 38 (67.9%)

Table 1. Demographic information of patients

Parameter	n (%)	Parameter	n (%)
Lenke classification		**Lenke saigttal thoracic modifier**	
1	19 (63.3)	-	5 (16.7)
2	1 (3.3)	N	23 (76.6)
3	8 (26.7)	+	2 (6.7)
5	2 (6.7)		
Lenke lumbar modifier		**Location apex**	
A	18 (60.0)	Thoracic	19 (63.3)
B	3 (10.0)	Thoracolumbar	8 (26.7)
C	9 (30.0)	Lumbar	3 (10.0)

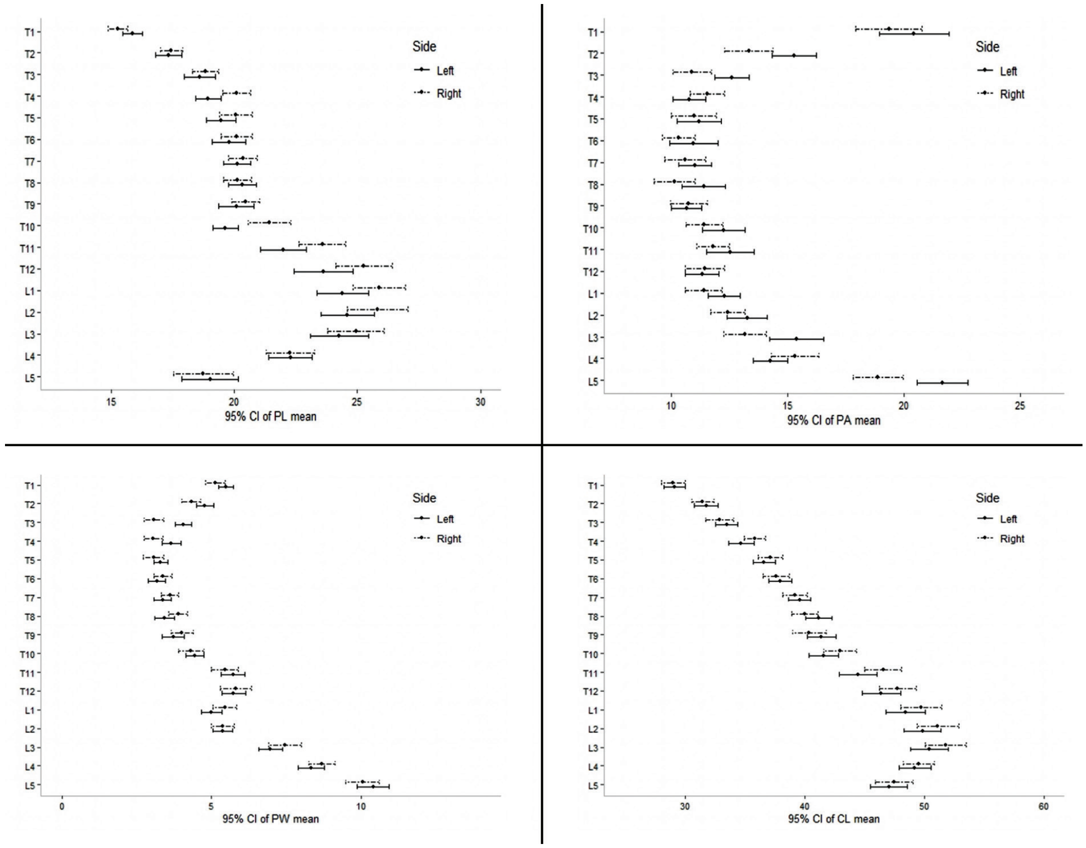

Figure 4. Mean and 95% confidence interval graph for T1-T12, L1-L5 pedicle length, axial pedicle angle, endosteal pedicle width and cord length values

CI: Confidence interval, PL: Pedicle length, PA: Pedicle angle, CL: Chord length

Table 2. T1-T12, L1-L5 pedicle length, axial pedicle angle, pedicle width and chord length values of the patients

	PL (mm)		APA (°)		PW (mm)		CL (mm)	
	Left	Right	Left	Right	Left	Right	Left	Right
T1	15.88±1.05	15.27±1.03	20.43±3.97	19.34±3.80	5.49±0.69	5.13±0.86	29.15±2.44	29.02±2.64
T2	17.34±1.42	17.45±1.24	15.28±2.54	13.32±2.80	4.79±0.78	4.34±0.85	31.80±2.68	31.49±2.54
T3	18.59±1.69	18.83±1.44	12.60±1.96	10.88±2.23	4.07±0.72	3.08±0.81	33.49±2.52	32.92±3.07
T4	18.94±1.40	20.10±1.55	10.76±1.85	11.54±1.96	3.66±0.85	3.06±0.79	34.71±2.79	35.85±2.43
T5	19.48±1.63	20.06±1.78	11.17±2.53	10.96±2.59	3.31±0.63	3.07±0.89	36.63±2.50	37.17±2.73
T6	19.79±1.85	20.11±1.70	10.95±2.81	10.31±1.90	3.18±0.77	3.38±0.82	37.96±2.63	37.65±2.94
T7	20.13±1.47	20.35±1.55	11.01±1.87	10.58±2.38	3.37±0.72	3.62±0.78	39.60±2.45	39.23±2.71
T8	20.14±1.51	20.34±1.51	11.38±2.51	10.12±2.40	3.43±0.88	3.89±0.83	41.20±2.92	40.05±2.92
T9	20.09±1.86	20.46±1.51	10.64±1.74	10.73±2.11	3.73±0.95	4.02±0.97	41.43±3.08	40.40±3.71
T10	19.65±1.39	21.44±2.32	12.23±2.43	11.41±2.15	4.45±0.83	4.32±1.13	41.59±3.27	42.98±3.63
T11	21.98±2.50	23.58±2.53	12.53±2.72	11.79±1.87	5.73±1.09	5.45±1.18	44.45±4.20	46.58±4.18
T12	23.63±3.21	25.26±3.08	11.31±1.94	11.43±2.26	5.74±1.06	5.82±1.38	46.41±4.27	47.78±4.13
L1	24.40±2.80	25.89±2.86	12.26±1.81	11.39±2.12	5.00±0.91	5.45±1.06	48.45±4.48	49.76±4.54
L2	24.60±2.89	25.83±3.27	13.26±2.32	12.42±2.00	5.37±0.90	5.39±1.02	49.86±4.16	51.14±4.62
L3	24.27±3.18	24.94±3.10	15.39±3.12	13.16±2.49	6.98±1.06	7.46±1.47	50.45±4.21	51.81±4.64
L4	22.28±2.38	22.26±2.64	14.25±1.95	15.29±2.74	8.34±1.18	8.69±1.18	49.23±3.64	49.53±3.51
L5	19.03±3.09	18.74±3.23	21.65±2.92	18.87±2.87	10.41±1.47	10.06±1.50	47.07±4.13	47.49±4.14

Data were expressed as mean ± SD. T: Thoracic, L: Lumbar, PL: Pedicle length, APA: Axial pedicle angle, PW: Pedicle width, CL: Chord length, SD: Standard deviation

Table 3. T1-T12, L1-L5 instrumentation and vertebral rotation rates of the patients (%)

	Instrument (n=27)*		Vertebral rotation (n=30)**						
	Right	Left	Left 75%	Left 50%	Left 25%	0%	Right 25%	Right 50%	Right 75%
T1	3.7	0.0			23.3	66.7	6.7	3.3	
T2	7.4	7.4			26.7	66.7	3.3	3.3	
T3	77.8	77.8			20.0	73.4	3.3	3.3	
T4	85.2	88.9			20.0	76.7			3.3
T5	77.8	92.6		3.3	6.7	63.3	23.4		3.3
T6	48.1	33.3			6.7	46.6	30.0	16.7	
T7	63.0	25.9			3.3	26.7	46.7	23.3	
T8	70.4	29.6			6.7	13.3	36.7	43.3	
T9	70.4	25.9			13.3	10.0	40.0	36.7	
T10	85.2	37.0		6.7	3.3	23.3	43.4	23.3	
T11	85.2	55.6		6.7	13.3	26.7	40.0	13.3	
T12	66.7	66.7	6.7	3.3	10.0	46.6	26.7	6.7	
L1	77.8	81.5	6.7	10.0	16.6	40.0	20.0	6.7	
L2	55.6	63.0		23.3	30.0	30.0	16.7		
L3	55.6	59.3		16.7	30.0	36.7	13.3	3.3	
L4	29.6	25.9			23.3	70.0	6.7		
L5	7.4	7.4			10.0	86.7	3.3		

*The proportion of the enstrume were given as percentage. ** Data were summarized as row percentage. T: Thoracic, L: Lumbar

Table 4. Correlations between patients' main thoracic Cobb angles and T1-T12, L1-L5 pedicle length, axial pedicle angle, pedicle width and chord length values*

	PL (mm)		APA (°)		PW (mm)		CL (mm)	
Cobb°	Left	Right	Left	Right	Left	Right	Left	Right
T1	-0.219	**-0.369***	**0.365***	0.339	-0.242	0.148	-0.256	-0.308
T2	-0.203	-0.042	0.228	0.230	0.130	0.187	-0.164	-0.119
T3	-0.329	-0.203	-0.039	0.131	0.206	-0.207	-0.303	0.131
T4	-0.356	-0.273	0.161	-0.015	0.119	-0.242	**-0.478***	-0.248
T5	**-0.485***	-0.226	-0.163	-0.121	0.154	-0.289	-0.331	-0.087
T6	**-0.371***	-0.030	-0.181	-0.114	-0.073	-0.114	**-0.458***	-0.188
T7	**-0.506****	-0.082	-0.308	-0.152	0.085	0.090	**-0.401***	-0.152
T8	-0.151	-0.045	-0.052	**-0.453***	-0.191	-0.098	-0.074	-0.172
T9	-0.248	-0.242	0.027	**-0.499***	0.003	-0.012	-0.324	-0.112
T10	0.034	0.016	-0.277	-0.273	-0.107	-0.003	-0.206	-0.220
T11	-0.125	-0.164	-0.124	-0.238	0.118	0.059	-0.272	-0.238
T12	-0.110	-0.076	0.211	-0.226	0.250	0.165	-0.101	-0.103
L1	-0.036	0.015	0.150	-0.259	0.214	0.263	-0.042	0.035
L2	-0.284	-0.079	-0.184	-0.199	0.348	0.157	-0.134	0.026
L3	**-0.508****	-0.201	-0.202	-0.110	0.213	0.156	-0.320	-0.045
L4	-0.049	0.147	-0.214	-0.296	0.304	**0.463***	0.014	0.169
L5	0.014	0.030	-0.262	-0.320	0.200	0.047	-0.141	-0.083

The Pearson correlation coefficients written in bold font are statistically significant (p<0.05).
Interpreting the size of the correlation coefficients (Mukaka, 2012):
0.00-0.29: Negligible
*: 0.30-0.49: Low correlation
**: 0.50-0.69: Moderate correlation
***: 0.70-0.89: High correlation
****: 0.90-1.00: Very high correlation
T: Thoracic, L: Lumbar, PL: Pedicle length, APA: Axial pedicle angle, PW: Pedicle width, CL: Chord length

of the 56 patients included in the study were females, which supported the results found herein.

In the AIS classification defined by the Lenke classification from types 1 to 6 was defined according to curvature and combined with lumbar modifiers (A, B, C) and sagittal thoracic modifiers (–, N, +)[27]. In the classification made by Farshad et al.[28] on 100 AIS patients, Lenke type 1 AIS was detected with the highest incidence, the most common type A was lumbar modifiers, and the most common type of normocyphosis (N) was determined as thoracic modifiers in the same patients. Similarly, in the current study evaluating 30 AIS patients, Lenke type 1, type A lumbar modifier and type N sagittal thoracic modifier patients were seen most frequently. Since the most frequently detected type 1 curvature was also the main thoracic type, the apex location was determined most frequently in the thoracic region in correlation with this.

EPW is an important factor determining the pedicle screw diameter. Larger diameter screws provide better tensile strength, increasing the stability of the structure[29]. The pedicle screw should be placed within the lateral and medial cortex. In a study conducted on Lenke type 1 AIS patients, it was reported that the EPW on the concave side of the thoracic spine was significantly smaller than on the convex side[6]. Parent et al.[30] examined the pedicle morphology on 325 scoliotic vertebrae, and similarly, the concave side of the thoracic curvature was narrower than the convex side, and they observed the greatest difference was in the T8 vertebra. In this study, the EPW was narrower on the left side with concavity in the thoracic region than on the right side with convexity, which supported the literature results. It was seen that the concave pedicles were narrower, especially in T6-9 vertebrae, where the apex of the thoracic deformity is located. Wang et al.[31] found that the mean distance from the spinal cord to the medial wall of the pedicle on the concave side was significantly less on the main thoracic curves than on the convex side of the apex. Thus, medial penetration of the deformity apex concave side pedicle screw may potentially increase the possible neurological complications.

Another parameter that should be considered when placing a pedicle screw is the APA. In the study conducted by Upendra et al.[12], the APA was higher on the concave side than on the convex side at all levels. Similarly, Hu et al.[6] showed that the APA was higher on the concave side when compared to the convex side, especially in the apical region, and they attributed this to the intervertebral deformation developed as a result of scoliosis rotation. In another study, it was reported that the APA

Table 5. Correlations between patients' vertebral rotation values and T1-T12, L1-L5 axial pedicle angle, pedicle width, and between axial pedicle angle and pedicle width values*

	Vertebral rotation					
	APA (°)		PW (mm)		APA - PW	
	Left	Right	Left	Right	Left	Right
T1	-0.332	-0.184	-0.047	0.336	0.151	-0.149
T2	0.023	-0.160	-0.201	0.080	0.126	0.095
T3	-0.293	-0.154	0.286	**0.400***	-0.239	-0.159
T4	-0.001	**0.393***	0.018	**0.573****	-0.024	0.338
T5	0.328	0.050	0.122	**0.429***	0.138	0.140
T6	0.172	0.156	**0.436***	**0.452***	0.347	0.036
T7	0.143	-0.121	**0.391***	**0.459***	0.287	-0.142
T8	0.229	-0.154	-0.019	0.355	0.058	-0.228
T9	-0.084	-0.270	0.190	**0.372***	0.056	-0.151
T10	-0.306	0.113	-0.268	0.130	0.109	-0.122
T11	-0.062	-0.127	-0.041	0.016	-0.302	-0.027
T12	-0.277	-0.176	-0.091	-0.033	0.110	0.226
L1	0.107	-0.031	0.145	-0.053	0.073	-0.108
L2	0.058	**0.417***	0.034	-0.067	-0.291	0.213
L3	-0.231	-0.150	-0.115	-0.311	**-0.577****	-0.286
L4	0.182	0.037	-0.229	-0.350	0.048	-0.196
L5	0.231	0.231	0.221	-0.074	-0.308	-0.301

The Pearson or Spearman correlation coefficients written in bold font are statistically significant (p<0.05).
Interpreting the size of the correlation coefficients (Mukaka, 2012):
0.00-0.29: Negligible
*: 0.30-0.49: Low correlation
**: 0.50-0.69: Moderate correlation
***: 0.70-0.89: High correlation
****: 0.90-1.00: Very high correlation
T: Thoracic, L: Lumbar, APA: Axial pedicle angle, PW: Pedicle width, Rotation: +/- 0-25%-50-75%-100%: [-4, +4]

in the convex pedicle was higher than in the concave side[11]. In the present study, however, no significant difference was found between the concave and convex sides. It was observed that the APA increased in the upper thoracic and lower lumbar vertebrae, with T1 being the highest.

One of the parameters that plays a role in deciding the length of the pedicle screw is the CL. In previous studies, it was recommended to place a pedicle screw with a length of at least 80% of the CL for a strong and stable fixation[32,33]. Hu et al.[6] showed that the CL in the apical region was slightly longer on the concave side compared to the convex side. Similar results were reported in another study on the scoliotic spine[34]. In this study, similar to the literature, a longer CL was measured on the left side, which is the concave side, especially in the apical regions, between T6 and T9.

The Nash-Moe index is a method used to clinically determine vertebral rotation, and it is a classification in which the apical vertebral body is divided into 6 equal parts longitudinally and the degree of rotation of the pedicles is decided according to their relationship with these lines[20]. In the study conducted by Mohanty et al.[35], higher Cobb angle values were measured at higher vertebral rotations compared to the Nash-Moe index. In a recent study, it was observed that the apical vertebral rotation was high, especially at the level of T6 to T9, where the Cobb angle was high.

It was aimed to clarify the relationship between the Cobb angle and pedicle morphology in AIS. In the study conducted by Davis et al.[5], adolescents with and without AIS were evaluated, and no significant relationship was found between the Cobb angle and pedicle morphology in either group. Liljenqvist et al.[11] also reported that there was no correlation between the Cobb angle and pedicle morphology. In the current study, the main thoracic Cobb angles of the patients were compared with the EPW, APA, PL, and CL, and no high correlation was observed at any level. On the other hand, in the current study, the APA and EPW were also evaluated in correlations with each other and with vertebral rotation. Again, no high or significant correlation was found at any level. It is a known fact that environmental and genetic factors are involved in the development and progression of deformity in AIS. Therefore, genetic, biomechanical, hormonal, and neurological factors that cause the AIS etiology of the patients may cause the components of the deformity to cause specific patterns for each patient. AIS can be a disease accompanied by developmental components.

Study Limitations

There are some limitations of this study. First, since the base points when measuring the parameters may vary, this may affect the measurement outcomes. Second, since the Nash-Moe index, which was chosen to evaluate the vertebral rotation, determines the degree of rotation in 25% of slices, it is very difficult to obtain the exact value. Finally, although the number of patients included in the study seemed relatively sufficient, studies with a larger number of patients will yield more precise results.

CONCLUSION

The pedicle morphology must be well defined for proper implantation of pedicle screws during surgical treatment of AIS. It was determined that the EPW was shorter and the CL was longer on the concave side of the vertebrae, especially in the apical region of the AIS deformity. Therefore, the special anatomical structure of this region should be taken into account in order to avoid possible neurological complications, especially in pedicle screw implantation in the apical concave region.

Ethics

Ethics Committee Approval: The study was approved by the Institutional Review Board of Ankara City Hospital (approval date: 09/22/2021, approval no: E1-21-2026).

Informed Consent: Informed consent was obtained from all patients to confirm their participation in the study.

Peer-review: Externally peer-reviewed.

Authorship Contributions

Surgical and Medical Practices: M.A.E.A., Concept: M.A.E.A., Design: M.A.E.A., C.Ç., Data Collection or Processing: C.Ç., M.B., Analysis or Interpretation: P.D., Literature Search: C.Ç., M.B., Writing: M.A.E.A., C.Ç.

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