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The radiographic parameter risk factors of rapid curve progression in Lenke 5 and 6 adolescent idiopathic scoliosis

A retrospective study

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Abstract

Various parameters related to growth and maturity have been shown to be risk factors for scoliosis curve progression. We previously identified correlations between curve progression and radiographic parameters in clinical practice, but there is a lack of research.

The aim of this study was to investigate and identify the radiographic parameters that are risk factors for rapid curve progression in Lenke 5 or 6 adolescent idiopathic scoliosis (AIS).

A retrospective review of patients who were prospectively enrolled at the initiation of brace wear and followed through completion of bracing or surgery was performed. The inclusion criteria were as follows: a Lenke type 5 or 6 classification, Risser sign grade 0 or 1 at the initial outpatient examination, a follow-up period of 6 months including a minimum of 4 follow-ups, At each visit, the whole spine x-ray was completed, the following data were measured and collected: angle of the lumbar curve (LC), rotation of the apical vertebra (RAV) in the LC, deviation of the apical vertebra (DAV) in the lumbar curve, clavicle angle, L5 tilt angle (TA), body mass index, flexibility of the LC (FLC), and peak angle velocity (PAV). A binary logistic regression analysis was used to assess the contribution of each variable to PAV onset. The touch types for the determination of the lowest instrumented vertebra (LIV) were compared at both the PAV and final follow-up.

Thirty-six AIS patients were recruited. The binary logistic regression model indicated that the following variable values significantly contributed to a high risk of PAV occurrence: LC ≥30° (OR = 6.153, 95%CI = 1.683–22.488, $P = .006$), RAV ≥III (OR = 15.484, 95% CI = 4.535–52.865, $P < .001$), DAV ≥40 mm (OR = 8.599, 95%CI = 2.483–29.784, $P < .001$), and TA ≥10° (OR = 2.223, 95%CI = 3.094–27.563, $P < .001$). The touch types for LIV determination changed in 12 of 36 patients, with at least 1 segment added as the LIV between the PAV and the final visit.

LC ≥30°, RAV ≥III, DAV ≥40 mm, and L5 TA≥10° were radiographic parameters associated with an increased risk of curve progression in Lenke 5 and 6 AIS. The orthopedic surgery performed at the PAV is the ideal timing, and it will preserve 1 active segment than later surgery.

Level of evidence was 4.

Abbreviations: AIS = adolescent idiopathic scoliosis, AP = anteroposterior, AV = angle velocity, BMI = body mass index, CA = clavicle angle, CI = confidence interval, CSVL = center sacrum vertical line, DAV = deviation of the apical vertebra, DSA = digital skeletal age, FLC = flexibility of the lumbar curve, IS = idiopathic scoliosis, LC = lumbar curve, LIV = lowest instrumented vertebra, MRI = magnetic resonance imaging, OR = odds ratio, PASC = picture archiving and communication systems, PAV = peak angle velocity, RAV = rotation of the apical vertebra, TA = tilt angle.

Keywords: curve progression, idiopathic scoliosis, peak angle velocity, radiographic parameters

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1. Introduction

Idiopathic scoliosis is scoliosis, that is, lateral curvature of the spine, is a structural alteration that occurs under a variety of conditions, for which there is no definite etiology, unlike neuromuscular, congenital, or syndromic types. And adolescent idiopathic scoliosis (AIS), which is IS at age $\geq$10 years, is the most common form of IS, accounting for between 80% and 85% of cases. There are many methods of AIS classification, but Lenke classification is the most classic, it was developed in 2001 to provide a comprehensive and reliable means to categorize and guide treatment. Lenke classification includes 6 categories; in Lenke types 5 and 6, the thoracolumbar/lumbar curve (LC) is the main curve.

Progression of the curvature during periods of rapid growth can result in significant deformity, which may be accompanied by cardiopulmonary compromise.[1–3] In general, for mild AIS, bracing treatment can control the curve progression, and surgical treatment is required for severe AIS. The treatment recommendations of the system state that major and structural minor curves are included in the instrumentation and fusion and that the nonstructural minor curves are excluded.[4,5] Orthopedic surgery is terrible for both the child and the family, so early treatment is key for AIS.

As growth continues, the curve in AIS progresses. Rapid curve acceleration during puberty presents considerable challenges in the prognosis of IS,[6,7] and previous researched found that the growth peak is the rapid development period of scoliosis, So the key to treating AIS is finding peak angle velocity (PAV).[8]

Previous studies have demonstrated that the risk factors for rapidly increased PAV include chronologic age, digital skeletal age (DSA) score, secondary sexual characteristics, Risser sign, age of menarche, and spinal growth velocity.[7,9–13] However, these risk factors all originate in the growth field. In outpatient follow-ups, we have found that curve progression occurred more rapidly in patients with some parameters about trunk imbalances; thus, we hypothesized that radiographic parameters also is the risk factors for PAV. The present study aimed to investigate and identify radiographic parameters that affect rapid curve progression in Lenke 5 and 6 AIS.

2. Materials and methods

2.1. Study design and setting

In this 2-site cohort and retrospective study, which was approved by the Changhai Hospital and Shanghai Tongren Hospital Ethical Committee (Number: 2016157; Date: 2016-12-9), physically immature Lenke 5 and 6 adolescent IS (AIS) patients were recruited from 2011–2009 to 2015–2012 (LC $\geq$20°). It is calculated that the sample size needs to be >36.

2.2. Participants

All the participants come from Changhai Hospital and Shanghai Tongren Hospital. All patients met the AIS diagnostic criteria: Cobb angle >10°, age 11–18 years, and the cause of scoliosis is unknown. All of the participants received brace treatment.

The inclusion criteria were as follows: patients undergoing standardized Boston brace treatment[14,15] with >75% compliance, which was ascertained by telephone interview with the parents of the patients: wearing of the brace for at least 10 hours each day was defined as compliance, otherwise, noncompliance was recorded[16]; a Risser sign of 0 or 1 at the initiation of bracing; a follow-up period of 6 months with a minimum of 4 follow-ups; a curve progression of >10° at the final follow-up, the cessation of brace treatment or patient submission to operation; the whole spine x-ray was completed at each follow-up; and a magnetic resonance imaging evaluation of the whole spine that indicated normal findings with the exception of scoliosis. The exclusion criteria included incomplete image data; patients with previous spinal surgery or abnormalities in maturation or height, such as a lower extremity growth deficiency or arrest; spinal cord abnormalities (i.e., tethered cord or Chiari malformations); and cardiopulmonary dysfunction.

2.3. Variables and data sources

The AIS patients were assessed every 6 months. At each visit, x-ray radiographs of the whole spine and left and right bending radiographs were obtained. Data on the following were collected and recorded at follow-up: LC, rotation of the apical vertebra (RAV), deviation of the apical vertebra (DAV), clavicle angle (CA), L5 tilt angle (TA), body mass index (BMI), and flexibility of the LC (FLC).

Note: The vertebra that has the largest rotation is defined as the AV, with the Nash–Moe method used to evaluate the degree of rotation (*I–V*). The rotation of the AV is defined as RAV, and the vertical distance between the geometric center of the AV and the center sacral vertical line is defined as the DAV.

On standing anteroposterior (AP) spinal radiographs during each visit, LC, RAV, DAV, CA, and TA were measured. FLC was measured using a bending radiograph and calculated as (LC–bending curve)/LC*100%.[17] Patient height and weight were used to calculate BMI, and the corresponding percentile categories were determined (1, BMI >85th percentile (high-BMI group); 2, BMI <20th percentile (low-BMI group); and 3, BMI=20–85th percentile (mid-BMI group)).[18,19] The angle velocity was calculated as (angle velocity$_n$ – angle velocity$_{n-1}$)/[time interval ($n-(n-1)$)] (where n represents the 1 visit, and $n-1$ represents the follow-up preceding n). PAV was defined as the peak of the scoliosis angle velocity curves during the entire follow-up period during puberty; it is a maximum value; PAV's judgment is the key to the study. All of the parameter measurements were performed by 2 independent surgeons with 2 repetitions, and the average value of the 4 measurements was calculated. All of the data were collected using picture archiving and communication systems technology.

For the standing AP spinal radiographs of the PAV and the final follow-up, the touch type (Fig. 1) was recorded to determine the lowest instrumented vertebra (LIV) and the number of different segments. The touch type represents the relationship between the lumbar vertebra and the center sacrum vertical line (CSVL).[20] Type A is touch without pedicle (beside the vertebra), type B is touch with pedicle, and type C is the CSVL in the middle of the pedicles. Touch type is similar to the lumbar modifier of Lenke classification[5]; however, touch type places more emphasis on the position relationship between the CSVL and pedicle, especially the pedicle of the first vertebra, which the CSVL touches from the sacrum to the thoracic vertebra. A typical case is shown in Figure 2A–C.

2.4. Statistical methods

Data were statistically analyzed using SPSS software V.18.0 (SPSS, Inc, Chicago, IL). Descriptive statistics were calculated to describe patient demographics. Quantitative variables are

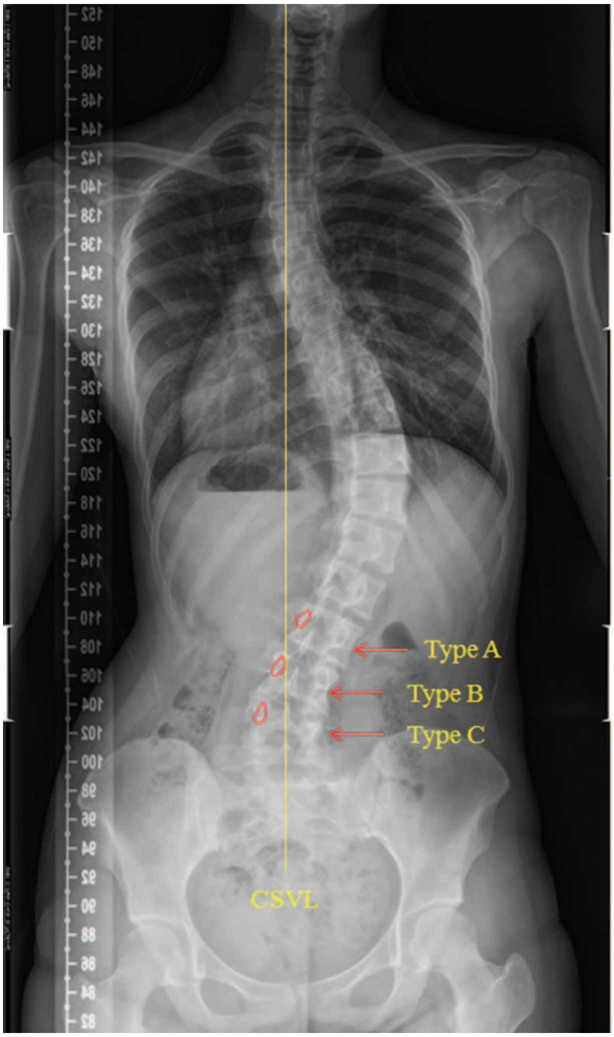

Figure 1. The positional relationship between the LIV and CSVL (the vertical line that bisects the proximal sacrum), called the touch classification, which was divided into 3 categories: type A, the CSVL was located in the LIV pedicle of the lateral side and did not touch the pedicle; type B, the CSVL touched the LIV pedicle; type C, the CSVL was located between the LIV bilateral pedicles. CSVL = center sacrum vertical line, LIV = lowest instrumented vertebra.

presented as the mean and standard deviation. Categorical variables were subjected to univariate analyses using the χ^2 test. Chi-square tests were utilized to compare the percentage distributions of different radiographic parameter risk factors in or beyond the PAV, which served as a preliminary screening tool to select potential candidates for the binary logistic regression analysis. A binary logistic regression analysis was conducted to identify the independent radiographic parameters that were high-risk predictors of PAV occurrence.

In the statistical analysis, PAV was coded as 0 for the nonoccurrence of PAV and 1 for PAV occurrence. LC was coded as 0 for <30° and 1 for ≥30°. CA was coded as 0 for <2° and 1 for ≥2°. RAV was coded as 0 for <III and 1 for ≥III. DAV was coded as 0 for <40 mm and 1 for ≥40 mm. TA was coded as 0 for <10° and 1 for ≥10°. BMI was coded as 0 for ≤20th percentile, 1 for 20–85th percentile, and 2 for ≥85th percentile. Flexibility was coded as 0 for <70% and 1 for ≥70%.[21] Statistical significance was set at a level of $P<.05$.

3. Results

Thirty-six Lenke 5 or 6 AIS patients (205 radiographs of both the spine and left and right bending radiographs) were included in the study. The patients were followed up for a minimum of 2 years and 4 times; the longest follow-up was 5 years and 10 times. The patients had a mean age of 11.2 ± 1.8 years at their first visit. The lumbar angles were 24.2 ± 4.7° and 30.7 ± 8.6° at the time of the initial and final visits, respectively. Eight patients had surgery prior to their sixth visit because of rapid curve progression (3 patients had surgery on their fourth visit, and 5 patients had surgery on their fifth visit), and 2 cases had surgery on their final visit (the sixth visit) (Figs. 3 and 4). The indications for surgery were LC ≥30°, Risser sign <V, DAV ≥10 mm, and RAV ≥III. The values of PAV, LC, CA, RAV, DAV, TA, BMI, and flexibility were 25.7 ± 5.9°, 2.3 ± 1.9°, 2.4 ± 1.2°, 14.0 ± 8.5 mm, 6.6 ± 3.1°, 56.9 ± 21.6, and 60.9 ± 23.7%, respectively (Table 1).

The associations between the radiographic parameter risk factors and PAV occurrence are shown in Table 2. A binary logistic regression model was applied to analyze the main effects of the potential radiographic-parameter risk factors on PAV occurrence. The following variable values significantly contributed to a high risk of PAV occurrence: LC ≥30° (OR = 6.153, 95%CI = 1.683–22.488, $P=.006$), RAV ≥III (OR = 15.484, 95% CI = 4.535–52.865, $P<.001$), DAV ≥40 mm (OR = 8.599, 95% CI = 2.483–29.784, $P<.001$), and TA ≥10° (OR = 2.223, 95% CI = 3.094–27.563, $P<.001$) (Table 3).

The touch type of 12 of the 36 cases changed between the PAV and the final visit. In 10 patients, 1 segment changed, and in 2 patients, 2 segments changed. Six of the 12 patients were >13 years of age, and 6 patients were <13 years of age (Table 4).

4. Discussion

The causes of curve progression in IS can be divided into 2 types: growth factors and the other factors, such as radiographic parameters. Regarding growth factors, it is widely accepted that curve progression in IS patients is closely associated with patient growth potential.[22] Previous studies have demonstrated that chronologic age, DSA scores, secondary sexual characteristics, Risser sign, age of menarche, and spinal growth velocity are associated with curve progression in IS patients.[7,9–13] However, during peak growth, scoliosis progresses rapidly. In the present study, some patients showed curve progression of ≥12° during the follow-up period. Thus, the risk factors associated with growth are insufficient for predicting the development of scoliosis. There is a lack of research on other risk factors, especially radiographic parameters factors. The effectiveness of brace treatment is approximately 50%.[23] In our clinical practice, we have determined that some LCs progress more rapidly than do thoracic curves. Among Lenke type 5 and 6 AIS patients in whom brace treatment has failed, it is debated whether early operation or conservative treatment is most appropriate. Because of the increase of curvature, the choice of the upper and lower fusion of the surgical scheme will differ. Thus, the optimal surgical time for some patients is missed because of rapid curve progression. Thus, we attempted to determine whether radiographic parameter factors correlate with curve progression and whether they can be used to guide surgical choices. We found that LC, RAV, DAV, and L5 TA are correlated with PAV occurrence. Among the 12 surgical patients, there were differences in the optimal lower end of the operation in PAV.

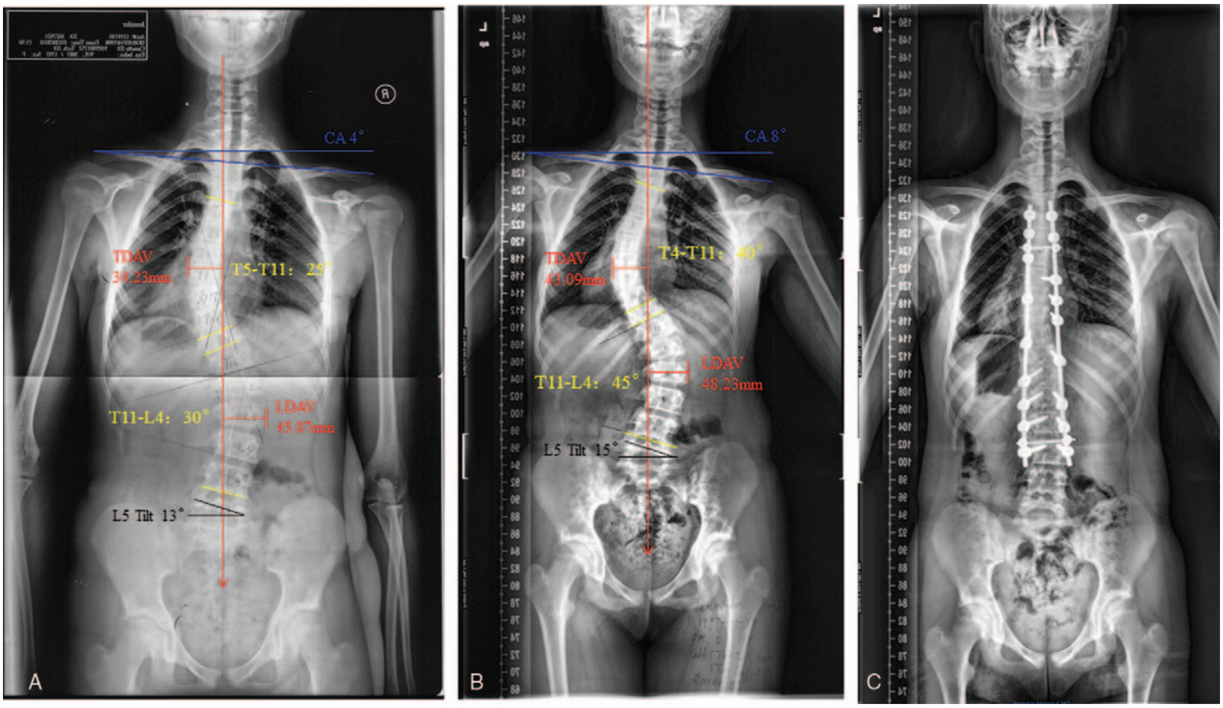

Figure 2. (A) The patient at the first visit. (B) After 3 months of brace treatment, the scoliosis curve had obviously progressed. (C) At 1-month follow-up after surgery.

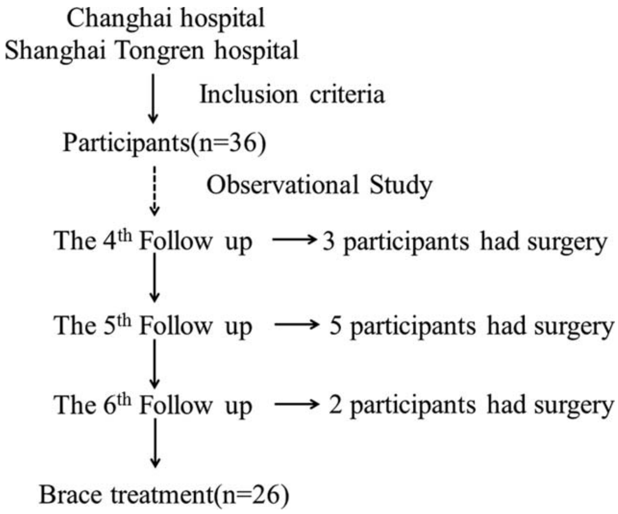

Figure 3. The change of patient quantity in different time points.

Table 1

summary of the general characteristics at PAV (n = 36).

	Mean ± SD
LC Cobb,°	25.7 ± 5.9
CA absolute value,°	2.3 ± 1.9
RAV, Nash–Moe	2.4 ± 1.2
DAV, mm	14.0 ± 8.5
L5 TA,°	6.6 ± 3.1
BMI, kg/m^2	36.9 ± 21.6
Flexibility, %	60.9 ± 23.7

BMI = body mass index, CA = clavicle angle, DAV = deviation of the apical vertebra, LC = lumbar curve, PAV = peak angle velocity, RAV = rotation of the apical vertebra, TA = tilt angle.

Shi et al[7] found that increased chronologic age, higher modified Risser sign, higher DSA score, higher height velocity, and higher spine length velocity tended to increase the risk of entering the rapid curve acceleration phase in girls with progressive IS. Little et al[11]

Table 2

Association between mechanical risk factors and occurrence of PAV.

	Items	Follow-up (n = 205)	PAV cases	Incidence of PAV	*P* value
LC Cobb					<.001
	<30°	141	14	10.0%	
	≥30°	60	22	36.7%	
CA absolute value					.531
	<2°	110	20	18.2%	
	≥2°	91	16	17.6%	
RAV					**.007**
	<III	125	15	12.0%	
	≥III	76	21	27.6%	
DAV					**.01**
	≥40 mm	106	26	24.5%	
	<40 mm	95	10	10.5%	
L5 TA					**.008**
	<10°	144	17	11.8%	
	≥10°	57	19	33.3%	
BMI					.777
	≥85th	51	10		
	20–85th	90	17		
	≤20th	60	9		
Flexibility					.572
	≥70%	126	21	18.1	
	<70%	75	15	17.6	

BMI = body mass index, CA = clavicle angle, DAV = deviation of the apical vertebra, LC = lumbar curve, PAV = peak angle velocity, RAV = rotation of the apical vertebra, TA = tilt angle.
Bold values mean *P* < .05.

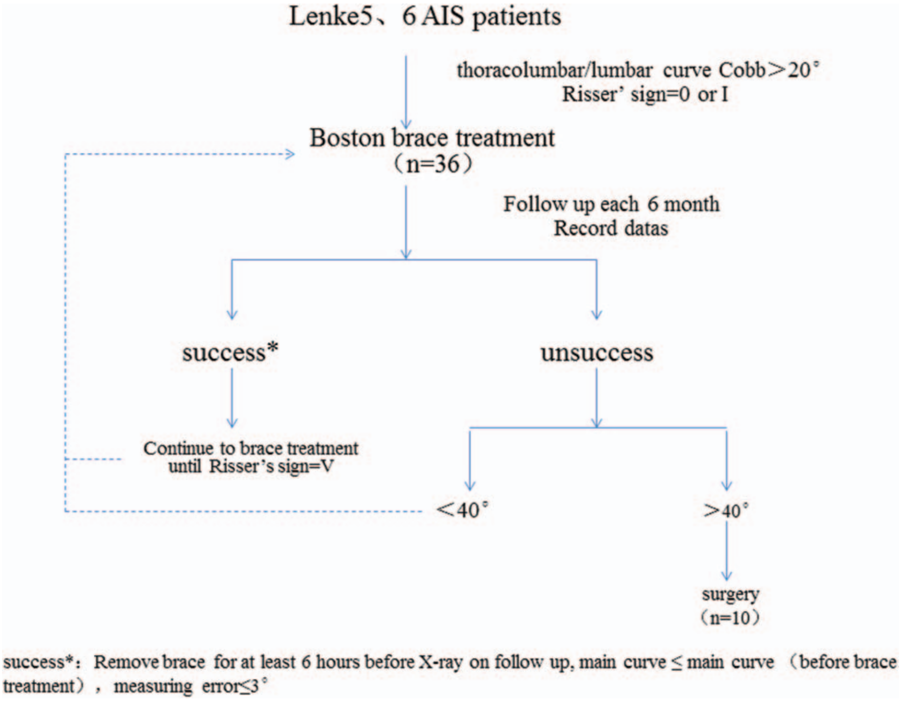

Figure 4. Selection criteria for treatment modality.

Table 3

Binary logistic regression analysis for risk factors.

	Correlation coefficient	OR	*P* value
LC Cobb	2.341	8.358	<.001
RAV	1.106	1.756	.020
DAV	1.638	3.645	.002
L5 TA	2.311	2.646	.030

DAV = deviation of the apical vertebra, LC = lumbar curve, OR = odds ratio, RAV = rotation of the apical vertebra, TA = tilt angle.

found that the height velocities generated from clinical height measurements for patients with IS documented the growth peak and reliably predicted the cessation of growth. Knowing the timing of the growth peak provides valuable information on the likelihood of progression to a magnitude requiring spinal arthrodesis. Dimeglio et al[8] reached a similar conclusion. The focus of these previous studies was on the factors associated with patient growth and not on radiographic parameters.

Lenke 5 or 6 AIS patients were selected as research subjects for several reasons. One reason is that Lenke 1 thoracic curves accept support and correction from the rib and cannot sufficiently reflect the effect of radiographic parameter factors, whereas the Lenke 5/6 curve is primarily a LC and can therefore sufficiently reflect the relationship between radiographic parameter factors and curve. Furthermore, the incidence of Lenke 5/6 is second only to that of Lenke 1.[5] Because scoliosis is a 3-dimensional deformity of the spinal coronal plane, sagittal plane, and transverse plane, we selected LC, RAV, DAV, CA, TA, BMI, and flexibility as variables to evaluate the LC.[24–26] PAV represents the peak

Table 4

The changes in the vertebral body when CSVL touch in PAV and final follow-up.

	Touch A			Touch B			Touch C		
	PAV	The last visit	Different vertebra number of gaps	PAV	The last visit	Different vertebra number of gaps	PAV	The last visit	Different vertebra number of gaps
1	L1	L3	2	L2	L4	2	L3	L5	2
2	L2	L3	1	L3	L4	1	L4	L5	1
3	L1	L2	1	L2	L3	1	L3	L4	1
4	L2	L3	1	L3	L4	1	L4	L5	1
5	L2	L3	1	L3	L4	1	L4	L5	1
6	L1	L2	1	L2	L3	1	L3	L4	1
7	L1	L3	2	L2	L4	2	L3	L5	2
8	L3	L4	1	L4	L5	1	L5	S1	1
9	L2	L3	1	L3	L4	1	L4	L5	1
10	L2	L3	1	L3	L4	1	L4	L5	1
11	L1	L2	1	L2	L3	1	L3	L4	1
12	L1	L2	1	L2	L3	1	L3	L4	1
Total			14			14			14

CSVL = center sacrum vertical line, PAV = peak angle velocity.

season of spine growth, which is the most rapid period of curve progression. Kato et al[27] considered the LC angle to have relationships with the rotation and DAV. Zhao et al[24] suggested that there is a correlation between trunk balance and each of CA and TA. Goodbody et al[19] suggested that results of brace treatment would be affected by BMI in children, with children of higher BMI having a greater incidence of brace treatment failure. Flexibility represents an important parameter for the evaluation of scoliosis; it not only is related to the length of time with scoliosis but can also guide the fusion segment.[28,29]

Chi-square tests indicated that LC ≥30°, RAV ≥III, DAV ≥40 mm, and TA ≥10° (all $P < .05$) were significantly different between the groups. The binary logistic regression analysis indicated that these 4 indicators are high-risk factors for PAV (all $P < .05$). The coefficient of RAV was the most predictive (coefficient=2.740, OR = 15.484). CA, BMI, and flexibility had no significant relationship with PAV ($P > .05$). Thus, the radiographic parameter factors were high-risk factors for curve progression; these findings contribute to our knowledge of the risk factors for PAV. The presence of a greater number of radiographic parameter factors is associated with increased likelihoods that the curve will rapidly progress and that surgery will be required.

To study the window of opportunity for operation, we selected the LIV as a research object in Lenke 5/6 patients and used the touch type to determine the LIV. The difference in the number of PAV segments between the first and final visit was analyzed. One-third of patients (12 cases) presented differences in LIV and differences in a minimum of 1 segment. Thus, the LIV extended from the PAV to the final visit. Our previous research considered touch type C to be the best LIV to decrease the incidence of addition. Touch type B is intermediate, whereas touch type C has the highest incidence of addition. In this study, we recommended that 6 of the 12 cases (with changed LIVs) who were >13 years of age should undergo surgery at the PAV rather than at the final visit because this would allow more active segments to be preserved and prevent an increase in the incidence of addition. Therefore, for a Lenke 5 or 6 patient >13 years of age with Risser sign ≥I, LC >30°, RAV >III, and DAV >40 mm, we recommend operation as soon as possible.

This study identified risk factors for curve progression in patients with TL/L curve that can be evaluated from radiography. Radiographic parameters can be used to predict the progress of scoliosis and guide the surgical treatment of AIS. Although this study identified radiographic parameters that are risk factors for PAV, it remains difficult to evaluate exactly when this PAV occurs. The limitations of the current study include the small sample size and the lack of an extended follow-up period. Furthermore, all of the patients underwent bracing treatment, which might have changed the natural history of the curve and thus our results from the natural course. Therefore, further studies are required. The presence of a greater number of radiographic parameter factors was associated with increased likelihoods that the curve would progress rapidly and that surgery would be required. The performance of surgery at PAV may preserve at least 1 active segment after surgery.

In the future, we should increase the verification research of 3-dimensional finite element or specimen to give support on basic research.

5. Conclusion

Some radiographic parameter factors, similar to growth factors, are high-risk factors for curve progression. LC ≥30°, RAV ≥III, DAV ≥40 mm, and L5 TA ≥10° were radiographic parameters associated with an increased risk of curve progression in Lenke 5 and 6 AIS. The orthopedic surgery performed at the PAV is the ideal timing, and it will preserve 1 active segment than later surgery.

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