Medicine®

OBSERVATIONAL STUDY

OPEN

Spontaneous Thoracic Curve Correction After Selective Posterior Fusion of Thoracolumbar/Lumbar Curves in Lenke 5C Adolescent Idiopathic Scoliosis

Fei Wang, MD, Xi-ming Xu, MD, Xian-zhao Wei, MD, Xiao-dong Zhu, MD, and Ming Li, MD

Abstract: Selective fusion of the thoracolumbar/lumbar (TL/L) curve is an effective method for the treatment of Lenke type 5C curves. Several studies have demonstrated that spontaneous correction of the thoracic curve does indeed occur. However, how this correction occurs after isolated posterior segmental instrumentation of the structural lumbar curve has not been well described.

The aim of this study was to evaluate the response of the thoracic curve to selective TL/L curve fusion in patients with Lenke type 5C adolescent idiopathic scoliosis (AIS) and assess the correlative clinical outcomes.

Thirty-four consecutive patients with Lenke type 5C AIS were included in this study. All patients underwent selective TL/L curve instrumentation and fusion via the posterior approach. Coronal and sagittal radiographs were analyzed before surgery, at 1 week after surgery and at least 2 years after surgery. The preoperative coronal Cobb angle of the major TL/L curve was $45.4^{\circ} \pm 7.0^{\circ}$, and that of the minor thoracic curve was $25.4^{\circ} \pm 8.8^{\circ}$. The major TL/L and minor thoracic curves were corrected to postoperative angles of $9.5^{\circ} \pm 5.0^{\circ}$ and $11.2^{\circ} \pm 5.2^{\circ}$, respectively, and measured $10.5^{\circ} \pm 6.0^{\circ}$ and $13.4^{\circ} \pm 7.5^{\circ}$ at the follow-up, respectively. The supine side-bending average Cobb angle of the thoracic curve was 9.9°. These results demonstrate satisfactory improvements because of coronal and sagittal restoration. Significant correlations were found between the preoperative and early postoperative conditions and the Cobb angle changes of the minor thoracic curve and the major TL/L curves ($r = 0.42$, $P = 0.01$). Significant correlations were also observed between the early and final follow-up postoperative conditions and the Cobb angle changes of the minor thoracic curve and the major TL/L curves ($r = 0.57$, $P < 0.001$). Significant correlations were observed between increased thoracic kyphosis (TK) and increased lumbar lordosis (LL) in the preoperative and early postoperative conditions ($r = 0.36$, $P = 0.035$) and between increased TK and increased LL in the preoperative and final follow-up postoperative conditions ($r = 0.51$, $P = 0.002$).

Spontaneous correction of the thoracic curve is a reflection of the TL/L curve correction in Lenke 5C AIS patients. Supine side-bending radiographs are an effective method of predicting the spontaneous correction of thoracic curves. The correction of LL is important for maintaining spinal sagittal alignment.

(*Medicine* 94(29):e1155)

Abbreviations: AIS = adolescent idiopathic scoliosis, AVT = apical vertebral translation, CB = coronal balance, L-AVT = lumbar AVT, LIV = lowest instrumented vertebra, LL = lumbar lordosis, PJA = proximal junctional angle, PJK = proximal junctional kyphosis, RSH = radiographic shoulder height, SVA = sagittal vertical axis, T-AVT = thoracic AVT, TK = thoracic kyphosis, TK = thoracic kyphosis, TL/L = thoracolumbar/lumbar, TS = trunk shift, UIV = upper instrumented vertebra.

Editor: Perbinder Grewal.
Received: April 17, 2015; revised: June 17, 2015; accepted: June 18, 2015.
From the Department of Orthopaedics, Changhai Hospital, the Second Military Medical University, Shanghai, China.
Correspondence: X-zW, X-dZ and ML, Department of Orthopaedics, Changhai Hospital, The Second Military Medical University, Shanghai 200433, China (e-mail: weixianzhao@126.com, scoliosis@126.com, limingspine@126.com).
FW, X-mX, and X-zW contributed equally to this manuscript.
The authors, their immediate families, and any research foundation with which they are affiliated did not receive any financial payments or other benefits from any commercial entity related to the subject of this article.
The authors have no conflicts of interest to disclose.

ISSN: 0025-7974
DOI: 10.1097/MD.0000000000001155

INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is a type of complex 3-dimensional structural deformity of the spine and is characterized by vertebral rotation in the transverse plane, lateral curvature in the frontal plane, and abnormal alignment in the sagittal plane. The operative goals of surgery in AIS are to obtain maximum correction of the curves, a well-balanced spine, and maximum functionality of the vertebral column. Surgical options consist of anterior, posterior, or combined procedures. However, with the development of instrumentation systems and surgical techniques, the posterior approach has become a popular treatment of thoracolumbar/lumbar (TL/L) curves in AIS.

Lenke type 5C AIS is characterized by a structural TL/L curve with a compensatory thoracic curve. Dwyer et al[1] reported the first use of an anterior approach in the corrective spinal surgery of patients with TL/L curves. The anterior approach of corrective spinal surgery achieves a shorter level of fusion and better correction of the coronal deformity.[2,3] However, the anterior approach may cause a kyphosing effect over the fused segments and is associated with a relatively high incidence of pseudarthrosis, respiratory compromise caused by the thoracoabdominal approach, a large vascular injury, a complex anatomic approach, and a cosmetically less acceptable scar.[1,4,5]

Harrington[6] first presented the posterior approach for treating TL/L curves using the hooks and rod system. Shufflebarger et al[7] found that the posterior treatment of TL/L with a wide posterior release and segmental pedicle screw instrumentation had excellent radiographic and clinical results with minimal complications. Bennett et al[8] showed that patients with AIS who underwent posterior pedicle screw instrumentation and spinal fusion for TL/L curves achieved improved correction in the coronal, sagittal, and axial planes. Several studies have reported a lack of significant difference in coronal or sagittal curve correction between anterior and posterior spinal fusion with a pedicle screw for the treatment of TL/L curves in AIS.[9–11] However, Geck et al[12] showed that adolescents with Lenke 5C curves obtained statistically significantly better curve correction, less loss of correction over time, and shorter hospital stays when treated with a posterior release and fusion via pedicle screws compared with anterior fusion via dual rods.

Huitema et al[13] and Senkoylu et al[14] showed spontaneous thoracic curve correction after the selective anterior fusion of thoracolumbar and lumbar curves, obtaining satisfactory results in the treatment of AIS. Many studies have also found that the improvement of the unfused thoracic curve occurs through posterior fusion of the TL/L curves.[3,7,8,15,16] However, few studies have focused in detail on the uninstrumented thoracic curves after the selective posterior fusion of the TL/L curves in Lenke 5C AIS patients. Therefore, the purpose of this study was to define radiographic and clinical outcomes of spontaneous thoracic curve correction after the selective posterior fusion of the TL/L curves in Lenke 5C AIS.

METHODS AND MATERIALS

Setting and Patient Population

Thirty-four consecutive patients with Lenke type 5C AIS were treated using one-stage TL/L posterior spinal instrumentation and fusion from June 2011 to February 2013. The inclusion criteria were as follows: diagnosis of AIS and age from 12 to 19 years; TL/L curve $>40^\circ$; no previous additional flexibility-modifying surgery; and a minimum of 2 years of follow-up. According to the classification scheme by Lenke et al[17], there were 9 patients with a sagittal thoracic ''–'' modifier and no patients with ''+'' modifiers. The Expedium instrumentation system (DepuySynthes, West Chester, PA) was utilized in all 34 cases. All surgical procedures were performed by 1 senior surgeon (M.L.). The study was approved by the clinical research ethics committee of our hospital.

Radiographic and Clinical Assessment

Preoperative, immediate postoperative (ie, the 1st week), and final follow-up radiographs were obtained on long cassettes by certified radiology technicians in a standardized fashion. Supine side-bending radiographs were obtained preoperatively for all patients. The parameters measured on the coronal radiographs were as follows: Cobb angle of the major TL/L curve; Cobb angle of the minor thoracic curve; coronal balance (CB); trunk shift (TS); radiographic shoulder height (RSH); apical vertebral translation (AVT); and lowest instrumented vertebra (LIV) tilt. CB was defined as the horizontal distance between the center of the S1 vertebra and a vertical line drawn from the center of C7. TS was the horizontal distance from the center sacral line to a line that bisected the distance between the lateral edges of the rib margins in the midthoracic area. RSH was the perpendicular distance in the soft tissue shadow directly superior to the acromioclavicular joint. Thoracic AVT (T-AVT) was the distance between the apical thoracic vertebra of the curve and the C7 vertebra plumb line. Lumbar AVT (L-AVT) was the distance between the apical lumbar vertebra of the curve and the C7 vertebra plumb line. LIV tilt was measured as the inclination in degrees of the inferior endplate relative to the horizontal plane. Five sagittal radiographic parameters were measured by thoracic kyphosis (TK), lumbar lordosis (LL), proximal junctional angle (PJA), and sagittal vertical axis (SVA). TK is the angle between the lines drawn from the T5 superior endplate and the T12 inferior endplate. LL is the angle between the lines drawn from the T12 superior endplate and the S1 inferior endplate. PJA is the angle between the lower endplate of the upper-instrumented vertebra (UIV) and the upper endplate of 2 vertebrae above UIV. SVA is the distance between the posterosuperior point of the sacral plate and the plumb line drawn from C7.

The Cobb angles were manually measured on all of the radiographs by 2 physicians, and the average values were obtained. An experienced spine surgeon reviewed the medical records and plain radiographs of all patients. The assessment of radiographs included preoperative standing posterior anterior (PA), supine side bending, and postoperative standing PA radiographs. The postoperative radiographic evaluation included the immediate postoperative and final follow-up radiographs.

The correction rate and flexibility rate were calculated as follows:

Formula 1:

Correction rate (%) = (Preoperative angle – Postoperative angle)/Preoperative angle × 100%.

Formula 2:

Flexibility rate (%) = (Preoperative standing angle – Preoperative bending angle)/Preoperative Cobb Angle × 100%.

Proximal junctional kyphosis (PJK) was defined as a PJA $>10^\circ$ and at least 10° greater than the corresponding preoperative measurement.

CB was graded as coronal decompensation (>2.0 cm), satisfactory (≤2.0 cm), and excellent (≤1.0 cm).

RSH was graded as significant imbalance (>3 cm), moderate imbalance (2–3 cm), minimal imbalance (1–2 cm), or balanced (<1 cm).

Statistical Analyses

Statistical analyses were performed using the SPSS statistical software v. 17.0 (SPSS Inc., Chicago, IL). Preoperative and postoperative radiographic parameters were compared using paired *t* tests. Pearson correlation coefficient was calculated using a linear regression analysis. The ''*r*'' correlation values were defined as follows: high correlation, 0.80 to 1.00; marked correlation, 0.60 to 0.79; and moderate correlation, 0.40 to 0.59; values >0.40 were defined as low or no correlation.[18] Statistical significance was defined as $P < 0.05$.

RESULTS

Patient Demographics

The study included 32 females (94.1%) and 2 males (5.9%). The mean age at the time of surgery was 15.4 ± 2.0 years (range: 12.0–19.0 years). The average time of the final follow-up was 32.5 ± 10.1 months (range: 24.0–60.0 months). The UIV was located at T8 in 1 patient, T9 in 11 patients, T10 in 14 patients, and T11 in 8 patients. The LIV was located at L3 in 7 patients, L4 in 22 patients, and L5 in 5 patients (see Table 1).

Coronal Plane Parameters

The coronal Cobb angle of the major TL/L curve was $45.9^\circ \pm 6.4^\circ$ (preoperative), $9.8^\circ \pm 4.8^\circ$ (immediate postoperative), and $10.3^\circ \pm 5.8^\circ$ (final follow-up). The Cobb angle of the minor thoracic curve was $25.4^\circ \pm 8.8^\circ$ (preoperative), $10.9^\circ \pm 4.9^\circ$ (immediate postoperative), and $12.3^\circ \pm 6.1^\circ$ (final follow-up). The rate of spontaneous correction was 55.4% for the minor thoracic curve. A significant difference was observed between the preoperative and immediate postoperative Cobb angles of the major and minor curve ($P < 0.001$). No significant

TABLE 1. preoperative and Postoperative Date for All Patients (N = 34)

Patients	Age, y	Sex	Curve Type	Final FU. mo	Main Curve	Minor Curve	Fusion Level	SB (°) (Major)	SB (°) (Minor)	TL/L Curve (°)			Thoracic Curve (°)			FR (%) (Major)	FR (%) (Minor)	CR (%) (Major, Post)	CR (%) (Major, FU)	CR (%) (Minor, Post)	lCR (%) (Minor, FU)
										Pre	Im-Post	FU	Pre	Im-Post	FU						
1	16	F	5CN	24	T10-L3	T6-T10	T10-L3	4	10	45	8	7	30	12	17	91	67	82	84	60	43
2	16	F	5CN	25	T11-L3	T7-T11	T9-L4	30	9	50	7	6	22	7	6	40	59	86	88	68	73
3	17	F	5CN	30	T10-L3	T5-T10	T9-L3	6	7	42	7	10	20	5	5	86	65	83	76	75	75
4	13	F	5CN	24	T10-L3	T6-T10	T9-L3	10	15	45	7	8	29	15	21	78	48	84	82	48	28
5	14	F	5C-	24	T10-L3	T6-T10	T9-L4	25	5	51	11	16	20	5	10	51	75	78	69	75	50
6	15	F	5CN	32	T12-L5	T5-T12	T11-L5	5	7	41	3	8	27	10	11	88	74	93	81	63	59
7	15	F	5CN	48	T10-L4	T5-T10	T10-L4	14	8	52	10	14	30	10	15	73	73	81	73	67	50
8	14	F	5CN	31	T11-L4	T6-11	T10-L4	20	18	58	14	10	42	20	20	66	57	76	83	52	52
9	18	F	5CN	24	T12-L4	T5-12	T11-L4	4	4	40	13	17	30	6	13	90	87	68	58	80	57
10	15	F	5C-	36	T12-L4	T6-T12	T11-L4	13	19	45	10	12	35	15	25	71	46	78	73	57	29
11	12	F	5CN	60	T10-L2	T5-T10	T9-L3	22	10	48	13	14	30	8	9	54	67	73	71	73	70
12	19	F	5CN	32	T11-L4	T7-T11	T11-L3	3	12	41	14	15	32	13	15	93	63	66	63	59	53
13	19	F	5CN	24	T10-L3	T4-T10	T9-L4	25	19	55	22	20	40	18	15	55	53	60	64	55	63
14	19	F	5C-	50	T10-L4	T3-T10	T9-L3	9	18	46	20	18	37	20	18	80	51	57	61	46	51
15	15	F	5CN	24	T11-L3	T5-T11	T11-L4	4	6	40	10	11	14	6	2	90	57	75	73	57	86
16	14	F	5CN	24	T12-L4	T6-T12	T11-L4	1	11	40	15	8	19	15	10	98	42	63	80	21	47
17	15	F	5C-	24	T11-L4	T5-T11	T10-L4	8	10	40	9	14	28	15	22	80	64	78	65	46	21
18	14	F	5CN	33	T10-L3	T4-T10	T9-L4	17	13	43	8	6	18	7	8	61	28	81	86	61	56
19	16	F	5CN	46	T11-L4	T6-T11	T10-L4	18	5	45	12	19	26	7	11	60	81	73	58	73	58
20	16	F	5CN	50	T11-L4	T5-T11	T10-L5	9	8	45	5	3	10	8	5	80	20	89	93	20	50
21	16	F	5CN	33	T11-L4	T5-T11	T10-L5	8	13	49	3	1	33	11	18	84	61	94	98	67	46
22	12	F	5CN	47	T11-L4	T5-T11	T10-L5	11	6	45	2	2	28	6	6	76	79	96	96	79	79
23	17	F	5CN	25	T11-L3	T5-T11	T10-L4	23	20	66	17	23	34	15	15	65	41	74	65	56	56
24	13	F	5CN	24	T11-L3	T6-T11	T10-L4	7	5	42	9	2	17	7	7	83	71	79	95	59	59
25	17	F	5CN	24	T10-L4	T5-T10	T10-L4	5	8	40	9	15	24	17	19	88	67	78	63	29	21
26	14	F	5CN	39	T11-L4	T6-T11	T10-L4	10	10	55	13	12	34	15	11	82	71	76	78	56	68
27	19	F	5CN	30	T11-L3	T4-T11	T9-L4	20	5	41	10	6	17	10	13	51	71	76	85	41	24
28	15	M	5CN	32	T9-L2	T4-T9	T8-L3	21	15	57	3	11	33	10	18	63	55	95	81	70	46
29	15	F	5CN	24	T11-L4	T4-T11	T10-L4	6	3	40	13	13	17	8	4	85	82	68	68	53	77
30	13	F	5CN	30	T10-L4	T5-T10	T9-L4	7	15	45	13	2	33	22	20	84	55	71	96	33	39
31	15	M	5CN	48	T10-L3	T7-T10	T9-L4	17	2	42	2	4	10	7	9	60	80	95	91	30	10
32	16	F	5CN	33	T12-L4	T7-T12	T10-L4	20	10	45	7	12	22	8	6	56	55	84	73	64	73
33	13	F	5C-	26	T12-L4	T8-T12	T11-L4	3	5	40	5	9	13	8	11	93	62	86	78	39	15
34	18	F	5C-	24	T12-L4	T9-T12	T11-L5	7	3	40	8	2	10	5	2	83	70	80	95	50	80
Mean	15.4			32.5				12.1	9.8	45.9	9.8	10.3	25.4	10.9	12.3	74.5	61.5	78.7	77.7	55.4	51.8
SD	2.0			10.1				7.8	5.1	6.4	4.8	5.8	8.8	4.9	6.1	15.0	15.0	10.0	12.0	15.9	19.7

CR = correction rate, FR = flexibility rate, FU = the final follow-up, Im-Post = immediate postoperative, Pre = preoperative, SB = supine bending, SD = standard deviation, TL/L = thoracolumbar/lumbar.

TABLE 2. Radiographic Assessment of Coronal Plane

Measurements	Preoperative	Immediate Postoperative	Final Follow-Up	*P* Value (Pre/Im-Post)	*P* Value (Im-Post/FU)	*P* Value (Pre/FU)
Major TL/L curve (°)	45.9 ± 6.4	9.8 ± 4.8	10.3 ± 5.8	<0.001*	0.493	<0.001*
Minor thoracic curve (°)	25.4 ± 8.8	10.9 ± 4.9	12.3 ± 6.1	<0.001*	0.056	<0.001*
CB, mm	20.7 ± 8.8	9.4 ± 3.5	10.5 ± 6.4	<0.001*	0.093	<0.001*
TS, mm	16.2 ± 7.5	9.7 ± 4.1	8.7 ± 6.6	<0.001*	0.207	<0.001*
RSH, mm	11.5 ± 5.8	8.0 ± 4.8	8.4 ± 5.9	0.005*	0.306	0.028*
T-AVT, mm	13.3 ± 5.2	8.8 ± 2.7	9.4 ± 4.5	<0.001*	0.265	<0.001*
L-AVT, mm	27.4 ± 11.2	10.7 ± 8.4	11.7 ± 8.1	<0.001*	0.111	<0.001*
LIV tilt (°)	23.5 ± 4.8	5.9 ± 2.3	6.3 ± 2.9	<0.001*	0.247	<0.001*

CB = coronal balance, FU = final follow-up, Im-Post = immediate postoperative, L-AVT = lumbar apical vertebral translation, LIV = lowest instrumented vertebra, Pre = preo-preoperative, RSH = radiographic shoulder height, T-AVT = thoracic apical vertebral translation, TS = trunk shift.
*Significant.

difference was found between the immediate and final follow-up postoperative Cobb angles of the major and minor curve ($P = 0.49$; $P = 0.056$) (Table 2; Figure 1).

The flexibilities of the major and minor curves were 74.5% ± 15.0% and 61.5% ± 15.0%, respectively, a statistically significant difference ($P = 0.001$).

Significant differences were found between the preoperative and the immediate postoperative CB, TS, RSH, T-AVT, L-AVT, and Cobb angles of the LIV tilt ($P < 0.001$, $P < 0.001$, $P < 0.005$, $P < 0.001$, and $P < 0.001$, respectively). However, there were no significant differences between the immediate and final follow-up postoperative CB, TS, RSH, T-AVT, L-AVT, and Cobb angle of the LIV tilt (see Table 2).

Sagittal Plane Parameters

Significant differences were observed among the preoperative, immediate postoperative, and final follow-up postoperative TK ($P < 0.05$). Significant differences were also found between the preoperative and the final postoperative LL ($P < 0.05$) and between the preoperative, immediate postoperative, and final follow-up PJA ($P < 0.05$). There were no significant differences among the preoperative, immediate postoperative, and final follow-up measurements of the SVA distance ($P > 0.05$) (Table 3; Figure 2).

Significant correlations were found between the preoperative thoracic and thoracolumbar Cobb angles ($R = 0.592$; $P < 0.001$; see Table 4), the immediate postoperative thoracic and thoracolumbar Cobb angles ($R = 0.538$; $P = 0.001$), and the flexibility rate of the thoracic curve and the immediate postoperative correction rate of the thoracic curve ($R = 0.415$; $P = 0.015$, see Table 3). The preoperative and immediate postoperative measurements revealed a significant correlation between a decrease in the thoracic curve and a decrease in the thoracolumbar curve ($R = 0.366$; $P = 0.033$). In the immediate and final follow-up postoperative measurements, a significant correlation was found in the change of the Cobb angles in the thoracic and thoracolumbar curves ($R = 0.491$; $P = 0.003$). Significant correlations were found between the preoperative

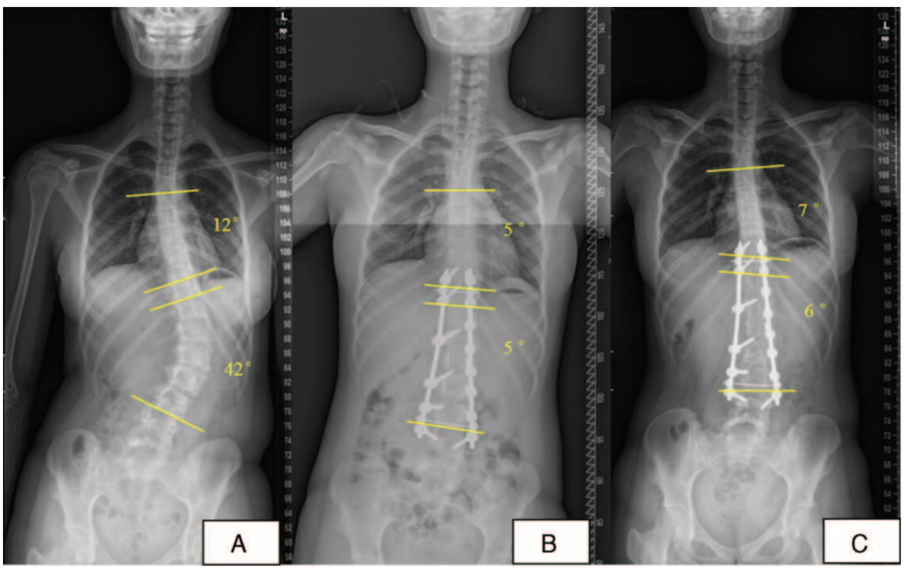

FIGURE 1. (A) Preoperative standing coronal radiograph of a 14-year-old female patient with adolescent idiopathic scoliosis and a main thoracolumbar/lumbar (TL/L) curve of 42° from T10 to L3 and a 12° compensatory thoracic curve. (B) Immediate postoperative standing coronal radiograph obtained after selective posterior instrumentation and fusion with pedicle screws from T9-L4, showing a 5° main TL/L curve and a 5° uninstrumented compensatory curve with satisfactory coronal and shoulder balance. (C) Two-year follow-up coronal radiograph showing a 6° main TL/L curve and a 7° uninstrumented compensatory curve.

TABLE 3. Radiographic Assessment of Sagittal Plane

Measurement	Preoperative	Immediate Postoperative	Final Follow-Up	*P* Value Pre/Im-Post	*P* Value Im-Post/FU	*P* Value Pre/FU
TK (°)	16.7 ± 9.8	20.9 ± 7.9	27.0 ± 11.0	0.018	0.001	<0.001
LL (°)	−50.4 ± 9.8	−53.7 ± 9.9	−58.1 ± 12.8	0.115	0.067	0.002
PJA (°)	3.0 ± 6.5	5.3 ± 5.1	10.3 ± 7.8	0.019	<0.001	<0.001
SVA, mm	−10.9 ± 33.2	−17.8 ± 32.3	−8.1 ± 26.0	0.315	0.107	0.665

FU = final follow-up, Im-Post = immediate postoperative, LL = lumbar lordosis, PJA = proximal junctional angle, Pre = preoperative, SVA = sagittal vertical axis, TK = thoracic kyphosis.

TK and LL ($R = 0.376$; $P = 0.028$), the immediate postoperative TK and LL ($R = 0.409$; $P = 0.016$), and the final follow-up postoperative TK and LL ($R = 0.490$; $P = 0.003$). The preoperative and immediate postoperative measurements revealed a significant correlation between the sagittal changes of TK and LL ($R = 0.474$; $P = 0.005$). In the immediate and final follow-up postoperative measurements, a significant correlation was found between the sagittal changes of TK and LL ($R = 0.474$; $P = 0.005$). However, no significant differences were found between preoperative TK and the thoracic curve corrections ($R = 0.09$; $P = 0.961$). A significant correlation was found between the final follow-up postoperative PJA and TK ($R = 0.732$; $P < 0.001$) and between the final follow-up postoperative PJK and LL ($R = 0.530$; $P = 0.001$). The preoperative and the final follow-up postoperative measurements revealed significant correlations between the PJA and TK changes ($R = 0.653$; $P < 0.001$) and between the PJA and LL changes ($R = 0.550$; $P = 0.001$). No significant difference was found between PJK and UIV ($R = 0.111$; $P < 0.532$).

DISCUSSION

Two approaches (anterior and posterior) can be used for the treatment of TL/L AIS patients. Anterior approach instrumentation and fusion has been widely accepted as a reliable and effective treatment for TL/L AIS patients.[2,13,14,19–21] However, some studies have found that the anterior method often results in problems with kyphosis, pseudarthrosis, and loss of correction.[1,4] Many studies have reported the spontaneous correction of an uninstrumented thoracic curve after anterior thoracolumbar correction and fusion.[2,9,13,14] Huitema et al[13] showed that the spontaneous thoracic curve correction is a reflection of the TL/L curve correction in Lenke 5C AIS patients; moreover, this group observed a significant correlation in the correction rates of the thoracolumbar and thoracic curves. In recent years, posterior correction and fusion have become popular treatments for TL/L AIS patients.[7,8,15,16,22,23] In the literature, several studies report spontaneous thoracic curve correction after posterior thoracolumbar correction.[7,8,16,22] However, no study has reported how the minor curves are expected to correct spontaneously after posterior thoracolumbar correction. We focused on the thoracic curve correction in the coronal and sagittal planes in Lenke 5C AIS patients receiving posterior TL/L fusion.

Spontaneous correction of the unfused thoracic curve has been demonstrated by many studies.[2,19,20,23,24] Sun et al[15] reported that the preoperative Cobb angle of the major TL/L curve was 44.1°, whereas the correction of the minor thoracic curve was 25.2°. At the final follow-up, the major TL/L and minor thoracic curves were corrected to 9.1° and 13.4°, respectively. Previously, we have calculated a 79.4% correction rate of major TL/L curves and a 46.8% spontaneous correction rate of thoracic curves.[15] In the present study, the correction rate of the

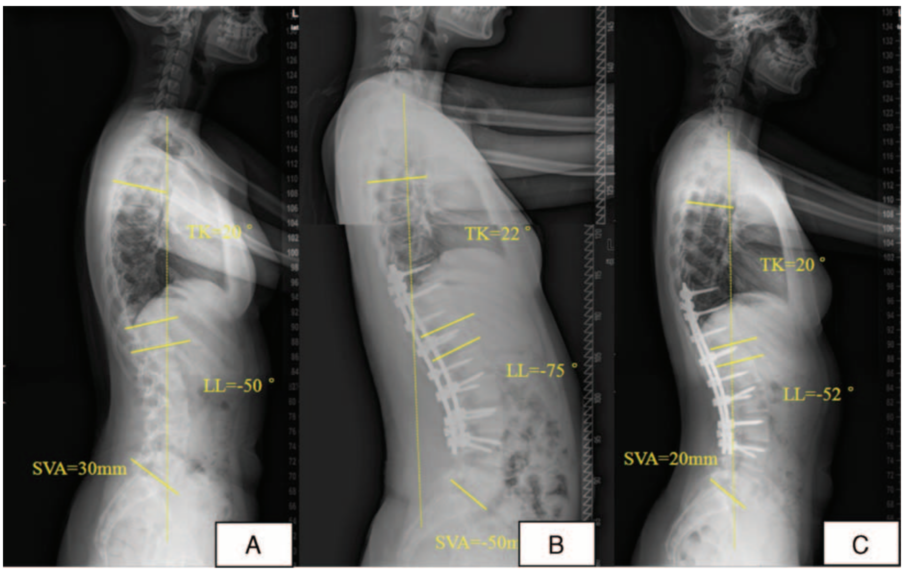

FIGURE 2. (A) Preoperative standing lateral radiograph. (B) Immediate postoperative standing lateral radiograph showing posterior instrumentation and fusion with pedicle screws from T9-L4. (C) Two-year follow-up lateral radiograph showing a satisfactory sagittal alignment.

TABLE 4. Statistics Result of the Linear Regression Analysis

Variables and Measurements		Correlation (R)	P Value
Pre-Cobb Th	Pre-Cobb ThL	0.592	<0.001*
Im-Post Cobb Th	Im-Post Cobb ThL	0.538	0.001*
FU Cobb Th	FU Cobb ThL	0.257	0.142
FR Th	Im-Post CR Th	0.415	0.015*
FR Th	FU CR Th	0.092	0.605
Im-Post CR Th	Im-Post CR ThL	0.138	0.435
FU CR Th	FU CR ThL	0.010	0.957
(Im-Post)-Pre Cobb Th	(Im-Post)-Pre Cobb ThL	0.366	0.033*
FU-(Im-Post) Cobb Th	FU-(Im-Post) Cobb hL	0.491	0.003*
Pre-TK	Pre-LL	0.376	0.028*
Im-Post TK	Im-Post LL	0.409	0.016*
FU TK	FU LL	0.490	0.003*
(Im-Post)-Pre TK	(Im-Post)-Pre LL	0.474	0.005*
FU-(Im-Post) TK	FU-(Im-Post) LL	0.613	<0.001*
FU PJA	FU TK	0.732	<0.001*
FU-Pre PJA	FU-Pre TK	0.653	<0.001*
FU-Pre PJA	FU-Pre LL	0.550	0.001*
PJK	UIV	0.111	0.532
Pre-TK	TCC	0.09	0.961

Cobb = Cobb angle, FR = flexibility rate, FU = final follow-up, Im-Post = immediate postoperative, LL = lumbar lordosis, PJK = proximal junctional kyphosis, Pre-TK = preo-preoperative TK, Pre = preoperative, TCC = thoracic curve correction, Th = thoracic curve, ThL = thoracolumbar curve, TK = thoracic kyphosis, UIV = upper instrumented vertebra.
*Significant.

major TL/L curve was 77.7% and the spontaneous correction rate of the thoracic curve was 51.8% at the final follow-up. Although Ilgenfritz et al[22] reported a 66% correction rate of the major TL/L and a 30% mean correction of uninstrumented compensatory thoracic curves at the 5-year follow-up, we failed to find a similar result. A noteworthy limitation of that study was that the included participants underwent different surgical techniques performed by distinct surgeons. Although both of these studies selected Lenke 5C AIS patients as subjects, the spontaneous thoracic curve correction rates were different. This discrepancy can be explained by the following 2 reasons: first, our study found that the flexibility of the thoracic curve was correlated with the immediate postoperative correction rate of the thoracic curve, that is, higher flexibility was associated with spontaneous correction; and second, the spontaneous thoracic curve correction can be affected by the TL/L curve correction. Although the correction rate of the thoracic curve was related to the correction rate of the TL/L curve after anterior correction and fusion, we found no significant correlation between the postoperative correction rates of the thoracic curve and the TL/L curve after posterior TL/L correction and fusion. However, we found a significant correlation between the decrease in the thoracic curve and the decrease in the thoracolumbar curve at the immediate postoperative measurements and a significant correlation between the changes in the Cobb angles in the thoracic and thoracolumbar curves at the final follow-up. These findings suggest that if the correction of the major curve was complete, the spontaneous correction and improvement of the minor curve may also be complete. Shufflebarger et al[7] reported the treatment of 62 patients with TL/L AIS through a wide posterior release and posterior pedicle screw to correct the TL/L curve, observing a correction rate of 80% and a 68% spontaneous correction rate of the thoracic curve with good coronal and sagittal alignments.

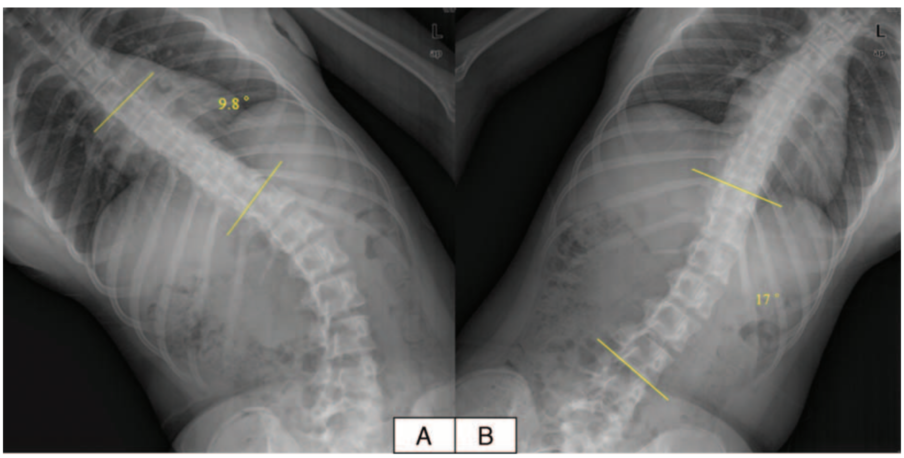

FIGURE 3. (A) Preoperative supine right-bending radiograph and (B) supine left-bending radiograph showing a 9.8° compensatory curve and a 17° main TL/L curve.

In our study, the coronal plane parameters significantly improved after the operations and remained stable at the final follow-up. The present results demonstrate that selective posterior fusion of the TL/L curves can promote the balance of the coronal plane. The preoperative evaluation of curve flexibility in AIS patients is essential for surgical planning and the estimation of clinical and radiographic outcomes. Li et al[16] suggested that Lenke 5C AIS patients with a preoperative thoracic curve >30° and a preoperative thoracic curve on bending >20⁰ might be suitable candidates for selective posterior TL/L curve fusion. In the present series of patients, the preoperative thoracic curve bent <20°. Therefore, the thoracic curve did not need to be fused. We also found a lack of significant difference between the supine side-bending Cobb angle (9.8°) and the immediate postoperative Cobb angle (10.9°) (Figure 3). Therefore, spontaneous minor curve correction may be predicted by supine side bending.

With regard to the sagittal balance of the patients, significant differences were found in the preoperative and immediate postoperative, immediate and final follow-up postoperative, and preoperative and final follow-up TK measurements. No significant differences were observed between the preoperative and immediate postoperative or the immediate and final follow-up postoperative LL measurements. However, a significant difference was observed between the preoperative and final postoperative sagittal Cobb angles of LL. The present study demonstrated that the stability of TK was not maintained. Sun et al[15] also reported that TK and LL were both increased at the immediate postoperative period compared with the preoperative period. Moreover, they observed that TK continuously increased during the follow-up period, whereas LL remained stable overall. Our results were similar to those of Sun et al.[15] Bennett et al[8] reported that TK remained stable from the first visit to the 5-year follow-up visit, whereas LL remained stable from the time of the preoperative radiographs to the 5-year follow-up visit. However, their inclusion criteria were different from ours. Our study found a significant correlation between the preoperative, immediate postoperative, and final follow-up postoperative TK and LL measurements. Significant correlations were found between the preoperative and immediate postoperative measurements of changes in TK and LL and between the immediate and final follow-up postoperative measurements of changes in TK and LL. These findings illustrate that the sagittal spontaneous correction of the thoracic area is also associated with the change in LL. Therefore, we suggest that the sagittal correction of LL is important for the stability of the sagittal alignment after selective posterior fusion of the TL/L curve in AIS. Excessive LL after surgery may result in an increased TK.

PJK is a common complication after spinal deformity corrective surgery and occurs more often following short segment instrumentation. Wang et al[25] reported an overall PJK incidence of 28% in AIS within 1.5 years after surgery, whereas Kim et al[26] reported a PJK incidence of 26% in AIS patients with a minimum 5-year follow-up. PJK occurred in 7 of 34 patients (21%) in our study. According to Sun et al,[15] an LIV location above or equal to L3, a higher postoperative L1, and deteriorative negative SVA with surgery are potential risk factors for increased PJA. However, these authors found no correlation between PJK and UIV, a result that was replicated in our study. A significant correlation was found between the final follow-up postoperative measurements of PJA and TK. Moreover, significant correlations were found between the changes in PJA and TK and between the changes in PJA and LL at the preoperative and final follow-up measurements. Therefore, we can infer that the incidence of PJK may be directly affected by TK and LL.

There are some potential limitations in this study. First, this was a retrospective study, which would endanger the strength of the conclusions. Second, the included patient number was relatively small. Multicenter large sample studies are required to further confirm our findings. However, the major strength of this study is the detailed description of the relationship between the lumbar curve corrections and the spontaneous thoracic curve corrections in both the coronal and sagittal planes. Moreover, the included participants were homogeneous and underwent surgical procedures with the same pedicle screw instrumentation performed by the same surgeon. In conclusion, the selective posterior fusion of the major TL/L curve is an effective method of treating Lenke 5C curves, resulting in satisfactory coronal and acceptable sagittal plane correction. The spontaneous correction of the thoracic curve is a reflection of the TL/L curve correction in Lenke 5C AIS patients. The use of supine side-bending radiographs is an effective method of predicting the spontaneous correction of uninstrumented compensatory curves. Finally, the correction of LL is important for maintaining the sagittal alignment after selective posterior fusion in Lenke 5C AIS patients.

REFERENCES

1. Dwyer AF, Newton NC, Sherwood AA. An anterior approach to scoliosis. A preliminary report. *Clin Orthop Relat Res*. 1969;62:192–202.
2. Sanders AE, Baumann R, Brown H, et al. Selective anterior fusion of thoracolumbar/lumbar curves in adolescents: when can the associated thoracic curve be left unfused? *Spine (Phila Pa 1976)*. 2003;28:706–713.
3. Lenke LG, Beta RR, Bridwell KH, et al. Spontaneous lumbar curve coronal correction after selective anterior or posterior thoracic fusion in adolescent idiopathic scoliosis. *Spine*. 1999;24:1663–1671.
4. Hsu LC, Zucherman J, Tang SC, et al. Dwyer instrumentation in the treatment of adolescent idiopathic scoliosis. *Bone Joint Surg Br*. 1982;64:536–541.
5. Kohler R, Galland O, Mechin H, et al. The Dwyer procedure in the treatment of idiopathic scoliosis. A 10-year follow-up review of 21 patients. *Spine (Phila Pa 1976)*. 1990;15:75–80.
6. Harrington PR. Treatment of scoliosis: correction and internal fixation by spine instrumentation. June 1962. *J Bone Joint Surg Am*. 2002;84-A:316.
7. Shufflebarger HL, Geck MJ, Clark CE. The posterior approach for lumbar and thoracolumbar adolescent idiopathic scoliosis: posterior shortening and pedicle screws. *Spine (Phila Pa 1976)*. 2004;29:269–276.
8. Bennett JT, Hoashi JS, Ames RJ, et al. The posterior pedicle screw construct: 5-year results for thoracolumbar and lumbar curves. *J Neurosurg Spine*. 2013;19:658–663.
9. Hee HT, Yu ZR, Wong HK. Comparison of segmental pedicle screw instrumentation versus anterior instrumentation in adolescent idiopathic thoracolumbar and lumbar scoliosis. *Spine (Phila Pa 1976)*. 2007;32:1533–1542.
10. Li M, Ni J, Fang X, et al. Comparison of selective anterior versus posterior screw instrumentation in Lenke5C adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)*. 2009;34:1162–1166.
11. Wang Y, Fei Q, Qiu G, et al. Anterior spinal fusion versus posterior spinal fusion for moderate lumbar/thoracolumbar adolescent idiopathic scoliosis: a prospective study. *Spine (Phila Pa 1976)*. 2008;33:2166–2172.

12. Geck MJ, Rinella A, Hawthorne D, et al. Comparison of surgical treatment in Lenke 5C adolescent idiopathic scoliosis: anterior dual rod versus posterior pedicle fixation surgery: a comparison of two practices. *Spine (Phila Pa 1976).* 2009;34:1942–1951.
13. Huitema GC, Jansen RC, van Ooij A, et al. Predictability of spontaneous thoracic curve correction after anterior thoracolumbar correction and fusion in adolescent idiopathic scoliosis. A retrospective study on a consecutive series of 29 patients with a minimum follow-up of 2 years. *Spine J.* 2015;15:966–970.
14. Senkoylu A, Luk KD, Wong YW, et al. Prognosis of spontaneous thoracic curve correction after the selective anterior fusion of thoracolumbar/lumbar (Lenke 5C) curves in idiopathic scoliosis. *Spine J.* 2014;14:1117–1124.
15. Sun Z, Qiu G, Zhao Y, et al. Risk factors of proximal junctional angle increase after selective posterior thoracolumbar/lumbar fusion in patients with adolescent idiopathic scoliosis. *Eur Spine J.* 2015;24:290–297.
16. Li M, Fang X, Sun Y, et al. Thoracic curve correction after posterior fusion and instrumentation of structural lumbar curves in patients with adolescent idiopathic scoliosis. *Arch Orthop Trauma Surg.* 2011;131:1375–1381.
17. Lenke LG, Betz RR, Clements D, et al. Curve prevalence of a new classification of operative adolescent idiopathic scoliosis: does classification correlate with treatment? *Spine.* 2002;27:604–611.
18. Franzblau A. A Primer of Statistics for Non-Statisticians. New York: Harcourt, Brace & World; 1958.
19. Sweet FA, Lenke LG, Bridwell KH, et al. Prospective radiographic and clinical outcomes and complications of single solid rod instrumented anterior spinal fusion in adolescent idiopathic scoliosis. *Spine (Phila Pa 1976).* 2001;26:1956–1965.
20. Satake K, Lenke LG, Kim YJ, et al. Analysis of the lowest instrumented vertebra following anterior spinal fusion of thoracolumbar/lumbar adolescent idiopathic scoliosis: can we predict postoperative disc wedging? *Spine (Phila Pa 1976).* 2005;30:418–426.
21. Wang T, Zeng B, Xu J, et al. Radiographic evaluation of selective anterior thoracolumbar or lumbar fusion for adolescent idiopathic scoliosis. *Eur Spine J.* 2008;17:1012–1018.
22. Ilgenfritz RM, Yaszay B, Bastrom TP, et al. Lenke 1C and 5C spinal deformities fused selectively: 5-year outcomes of the uninstrumented compensatory curves. *Spine (Phila Pa 1976).* 2013;38:650–658.
23. Okada E, Watanabe K, Pang L, et al. Posterior correction and fusion surgery using pedicle-screw constructs for Lenke type 5C adolescent idiopathic scoliosis: a preliminary report. *Spine (Phila Pa 1976).* 2015;40:25–30.
24. Takahashi J, Newton PO, Ugrinow VL, et al. Selective thoracic fusion in adolescent idiopathic scoliosis: factors influencing the selection of the optimal lowest instrumented vertebra. *Spine (Phila Pa 1976).* 2011;36:1131–1141.
25. Wang J, Zhao Y, Shen B, et al. Risk factor analysis of proximal junctional kyphosis after posterior fusion in patients with idiopathic scoliosis. *Injury.* 2010;41:415–420.
26. Kim YJ, Bridwell KH, Lenke LG, et al. Proximal junctional kyphosis in adolescent idiopathic scoliosis following segmental posterior spinal instrumentation and fusion: minimum 5-year follow-up. *Spine (Phila Pa 1976).* 2005;30:2045–2050.