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# Long-Term Follow-up of Posterior Selective Thoracolumbar/Lumbar Fusion in Patients With Lenke 5C Adolescent Idiopathic Scoliosis: An Analysis of 10-Year Outcomes

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## Abstract

**Study Design:** Retrospective study.

**Objective:** The aim of this study was to assess long-term radiographic and clinical outcomes in Lenke 5C adolescent idiopathic scoliosis (AIS) patients after posterior selective fusion.

**Methods:** Lenke 5C AIS patients who underwent posterior selective thoracolumbar/lumbar (TL/L) fusion in our hospital from January 2007 to January 2010 were recruited. Radiographic parameters were measured preoperatively and at the 3-month, 1-year, 2-year, 5-year, and 10-year follow-ups. The SRS-22 (Scoliosis Research Society) questionnaire was used to assess the clinical outcomes.

**Results:** We included 37 patients who underwent posterior selective TL/L fusion surgery in our study, and the mean follow-up time was 11.26 ± 0.85 years. The average preoperative Cobb angles of the thoracic and TL/L curves were 24.0 ± 9.0° and 45.4 ± 6.3°, respectively, which were corrected to 12.2° and 12.4° at the 3-month follow-up postoperatively, with correction losses of 2.2° and 1.5° at the 10-year follow-up. In the sagittal plane, the degree of thoracic kyphosis (TK) gradually increased over the follow-up period. The proximal junctional angle (PJA) also gradually increased from 6.7 ± 4.6 to 13.7 ± 5.6 during the follow-up period. For the clinical outcomes, correction surgery improved the SRS-22 scores in each domain, especially in the self-image domain.

**Conclusions:** Posterior selective TL/L fusion can effectively correct spinal deformities, leading to stable outcomes for 10 years postoperatively. During the follow-up period, the degree of TK presented an increasing trend that remained almost constant after the 1-year follow-up. Moreover, the variation in the PJA was highly significant in the postoperative period, and it showed an increasing trend until the 2-year follow-up.

**Keywords**
AIS, thoracolumbar/lumbar curve, posterior selective fusion, long-term outcome, radiographic

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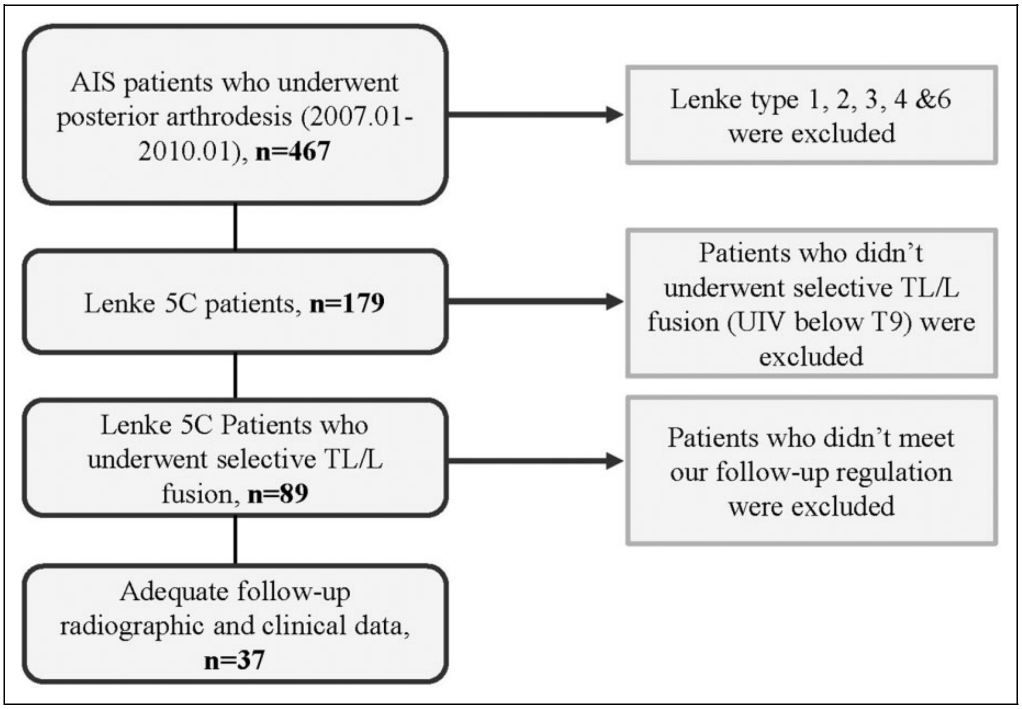


**Figure 1.** Flow chart showing the process of selection.

Lenke type 5C adolescent idiopathic scoliosis (AIS) is characterized by a structural thoracolumbar/lumbar (TL/L) curve with a compensatory thoracic curvature.[1] Both posterior and anterior spinal fusion techniques have been used to treat Lenke type 5C AIS patients in recent years. With advancements in pedicle screw fixation, the posterior approach is becoming more widespread and is considered reliable and effective.[2] Compared to the anterior approach, posterior spinal surgery has the advantages of yielding larger coronal corrections, a shorter length of hospital stay, a smaller degree of correction lost over time, and a lower pseudarthrosis rate. However, the optimal surgical treatment for patients with Lenke type 5C AIS is still controversial. When formulating a proper surgical strategy, the goal for both surgeons and patients is to spare as much motion in the unaffected segments as possible.[3] Therefore, Lenke et al[4] advised that fusion surgeries should include the TL/L region, and these types of surgery are called selective fusion.

Nevertheless, related radiographic and clinical complications caused by posterior procedures, such as the adding-on phenomenon,[5,6] coronal imbalance,[7] and proximal junctional kyphosis,[8] should be seriously considered. Currently, the widely accepted standard length of follow-up used to assess AIS orthopedic surgeries is 2 years.[9] However, as AIS patients grow from students to independent adults, changes can occur. Moreover, whether thoracic curves can spontaneously correct, global balance can be restored, and related complications remain immutable remain unknown. Therefore, long-term follow-ups are necessary and meaningful. Louer et al[10] reported that selective fusion of the primary TL/L curve results in spontaneous correction of the uninstrumented curve and improves coronal balance, which can be maintained for at least 10 years. However, posterior pedicle screw constructs for TL/L curves were used in 3 patients only in their study cohort. The purpose of this study was to assess long-term radiographic and clinical outcomes associated with spontaneous curve correction, coronal balance, sagittal balance, and potential complications in Lenke 5C AIS patients with posterior selective TL/L fusion.

## Methods and Materials

### *Study Design and Patient Population*

Lenke 5C AIS patients who underwent posterior selective TL/L fusion in our hospital from January 2007 to January 2010 were recruited. The inclusion criteria are shown in Figure 1 as follows: (1) AIS patients classified as having Lenke type 5C curves and no history of an additional flexibility-modifying surgery; (2) patients with a TL/L curve of more than 40° who underwent selective TL/L fusion, with the upper instrumented vertebra being T9 or an inferior vertebra; (3) patients with at least 10 years of follow-up; and (4) patients with radiographic measures collected preoperatively, at the first in-clinic assessment after the operation (generally 3 months), and at 1 year, 2 years, 5 years, and 10 years postoperatively. This study was approved by the institutional review board at our hospital.

### *Surgical Technique*

Lenke 5C AIS patients who were undergoing posterior procedures were placed in the prone position on a Jackson radiolucent spinal table after general anesthesia was induced. The surgeon made a midline incision and dissected the paraspinal muscle to the tip of the transverse process at all levels of spinal fusion. All the included patients underwent posterior pedicle screw instrumentation with arranged intervals and alternate screw instrumentation on the convex or concave side according to their spinal flexibility. Posterior release consisted of extensive facetectomies, and local bone grafts harvested from the compound of posterior elements and allogeneic bone were used to promote fusion. Curve correction was achieved using a lifting tool from both ends toward the middle, followed by a slight concave distraction and convex compression. Somatosensory-evoked potentials were routinely assessed for the intraoperative monitoring of spinal cord function. Finally, a subfascial drain was inserted before the completion of the surgery. All operations were performed by a single experienced spine surgeon with professional spine assistants using the same operative technique.

### Data Collection and Clinical Assessment

Preoperative and 3-month, 1-year, 2-year, 5-year, and 10-year postoperative radiographs were obtained on long cassettes in accordance with standardized protocols. Supine side-bending radiographs were taken preoperatively for all patients.

Demographic data, including sex, age, and body mass index (BMI), was recorded. Three surgeons individually measured radiological parameters using Surgimap software and then calculated the mean value. The parameters recorded in the coronal plane included the Risser sign, upper instrumented vertebra (UIV), lower instrumented vertebra (LIV), number of fused vertebrae, number of pedicle screws, thoracic and TL/L Cobb angles, translation of the thoracic apex (the distance between the vertebra at the apex of the thoracic curve and C7 plumb line [C7PL]), TL/L Cobb angle, translation of the lumbar apex (the distance between the vertebra at the apex of the lumbar curve and central sacral vertical line [CSVL]), radiographic shoulder height (RSH; the difference in soft tissue shadow directly superior to the acromioclavicular joint on standing anteroposterior radiographs), coronal balance (the horizontal distance between the center of the S1 vertebra and vertical line drawn from the center of C7 [C7-CSVL]), and trunk shift (TS; the horizontal distance from the center sacral line to a line that bisects the lateral distance from the lateral edges of the rib margins in the midthoracic area). The parameters measured in the sagittal plane included the degree of thoracic kyphosis (TK; the Cobb angle between the upper endplate of the T4 vertebra and the lower endplate of the T12 vertebra), degree of lumbar lordosis (LL; the Cobb angle between the upper endplate of the L1 vertebra and the lower endplate of the S1 vertebra), thoracolumbar junctional angle (TJLA; the Cobb angle between the upper endplate of the T10 vertebra and the lower endplate of the L2 vertebra), sagittal vertical axis (SVA; the horizontal offset from the posterosuperior corner of S1 to the vertebral body of C7), and proximal junctional angle (PJA; the angle measured from the caudal endplate of the UIV to the cranial endplate of 2 supra-adjacent vertebrae above the UIV).

**Table 1.** Demographic and Clinical Characteristics of All Subjects.

| Variables (N = 37) | Value |
|---|---|
| Age at surgery (years) | 15.27 ± 1.81 |
| Gender (female/male) | 35/2 |
| Follow-up (years) | 11.26 ± 0.85 |
| Body mass index | 18.13 ± 1.52 |
| Risser sign | 3.92 ± 1.06 |
| Thoracic BCR (%) | 64.8 ± 21.3 |
| Lumbar BCR (%) | 76.2 ± 14.6 |
| Lenke sagittal modifier | |
| — | 8 |
| N | 29 |
| No. of fusion vertebra (N) | 7.03 ± 0.80 |
| No. of pedicle screw (N) | 12.54 ± 1.32 |
| Implant density | 1.80 ± 0.17 |
| UIV (T8/T9/T10/T11) | 1/12/16/8 |
| LIV (L3/L4/L5) | 10/23/4 |
| Operative time (minutes) | 175.84 ± 42.04 |
| Intraoperative blood loss (mL) | 606.35 ± 220.03 |
| Thoracic final correction rate (%) | 38.4 ± 16.5 |
| Lumbar final correction rate (%) | 70.0 ± 8.7 |

Abbreviations: BCR, bending correction rate; UIV, upper instrumented vertebrae; LIV, lower instrumented vertebrae.

In addition, the thoracic and TL/L Cobb angles on preoperative supine side-bending radiographs were also obtained to assess flexibility.

Coronal decompensation was defined as a distance of >2 cm between the C7 plumb line and the CSVL. According to the Lenke sagittal modifier classification, TK <10° corresponded to a negative sign or hypokyphosis, while 10° ≤ TK ≤ 40° indicated normal values of kyphosis. PJK was defined as PJA ≥ 10°.

The Scoliosis Research Society questionnaire (SRS-22) was given to the patients at each follow-up for the assessment of health-related quality of life.

### Statistical Analyses

Statistical analysis was performed using SPSS 19.0 statistics software (SPSS Inc). Descriptive statistics are listed as the mean ± standard deviation (SD). Repeated-measures analysis of variance was used to assess the difference in the follow-ups postoperatively. When there was a significant difference, the Student-Newman-Keuls (SNK) method was used for pairwise comparisons. Paired *t* tests or Mann-Whitney *U* tests were used to analyze the quantitative data. Statistical significance was defined as $P < .05$.

## Results

### Patient Demographics

Of the 37 patients in our current series, 35 were female, and 2 were male. The average age at the time of surgery was 15.27 ± 1.81 years old. The average length of follow-up was 11.26 ± 0.85 years. The average Risser sign was 3.92 ± 1.06°. In addition, BMI at the time of surgery was calculated to be

**Table 2.** Radiographic Results Preoperatively and Long-Term Follow-up Postoperatively in Lenke 5C Patients.

| | Preoperative | 3 months postoperative | 1 year postoperative | 2 years postoperative | 5 years postoperative | 10 years postoperative | *P* value (among postoperative follow-up) | *P* value (preoperative vs 3 months postoperative) | *P* value (1 year vs 3 months postoperative) | *P* value (2 years vs 1 year postoperative) | *P* value (5 years vs 2 years postoperative) | *P* value (10years vs 5 years postoperative) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coronal plane | | | | | | | | | | | | |
| MT | 24.0 ± 9.0 | 12.2 ± 6.5 | 13.2 ± 7.5 | 13.3 ± 6.0 | 14.2 ± 5.3 | 14.4 ± 5.0 | **.046** | <**.001** | .521 | .972 | .533 | .917 |
| TL/L | 45.4 ± 6.3 | 12.4 ± 4.7 | 12.6 ± 3.8 | 13.0 ± 3.9 | 13.7 ± 3.5 | 13.9 ± 3.5 | .061 | <**.001** | .811 | .730 | .473 | .852 |
| AVT (T) | 11.6 ± 6.7 | 7.2 ± 3.5 | 9.0 ± 2.7 | 9.6 ± 2.7 | 10.4 ± 2.5 | 10.8 ± 3.3 | <**.001** | <**.001** | .041 | .468 | .381 | .650 |
| AVT (TL/L) | 29.5 ± 8.6 | 16.2 ± 5.0 | 17.4 ± 4.3 | 18.0 ± 4.5 | 18.5 ± 4.1 | 18.6 ± 3.7 | **.002** | <**.001** | .356 | .629 | .660 | .947 |
| RSH | 13.2 ± 6.8 | 8.3 ± 3.8 | 8.1 ± 3.6 | 7.7 ± 3.4 | 7.7 ± 3.4 | 8.0 ± 3.2 | .765 | <**.001** | .823 | .716 | .978 | .758 |
| TS | 17.1 ± 7.9 | 8.6 ± 3.9 | 9.9 ± 5.3 | 9.9 ± 4.9 | 9.4 ± 3.6 | 9.9 ± 3.2 | .284 | <**.001** | .262 | .982 | .680 | .697 |
| CB | 20.7 ± 9.2 | 12.2 ± 4.5 | 10.3 ± 6.3 | 11.6 ± 5.1 | 12.3 ± 4.8 | 13.1 ± 4.5 | .068 | <**.001** | .175 | .382 | .614 | .522 |
| Sagittal plane | | | | | | | | | | | | |
| TK | 18.4 ± 8.7 | 21.8 ± 9.4 | 28.2 ± 10.7 | 29.1 ± 9.0 | 30.2 ± 7.5 | 30.8 ± 7.0 | <**.001** | .097 | **.002** | .634 | .606 | .751 |
| TJLA | 7.9 ± 5.6 | 7.6 ± 8.7 | 7.8 ± 4.9 | 7.5 ± 3.4 | 8.9 ± 3.4 | 9.5 ± 3.6 | .276 | .808 | .843 | .774 | .270 | .627 |
| LL | 50.0 ± 9.4 | 53.6 ± 9.2 | 56.1 ± 11.1 | 56.6 ± 10.7 | 57.1 ± 10.5 | 57.4 ± 10.0 | .062 | .136 | .279 | .855 | .819 | .909 |
| SVA | 29.2 ± 19.7 | 31.7 ± 18.6 | 22.3 ± 14.6 | 25.3 ± 13.0 | 24.7 ± 9.6 | 25.1 ± 7.6 | .034 | .473 | **.006** | .368 | .854 | .917 |
| PJA | 6.2 ± 3.5 | 6.7 ± 4.6 | 11.1 ± 6.4 | 13.2 ± 6.1 | 13.7 ± 5.6 | 14.0 ± 5.8 | <**.001** | .769 | **.005** | **.043** | **.048** | .769 |

Abbreviations: TL/L, thoracolumbar/lumbar; AVT, apical vertebrae translation; RSH, radiographic shoulder height; TS, trunk shift; TK, thoracic kyphosis; TJLA, thoracolumbar junctional angle; LL, lumbar lordosis; SVA, sagittal vertical axis; PJA, proximal junctional angle; MT, main thoracic, CB, coronal balance.
The values in boldface means the difference was statistically significant.

18.13 ± 1.52 kg/m$^2$. The distribution of the Lenke sagittal modifier classifications showed that 8 cases were negative and 29 cases were normal (Table 1).

The average number of fused vertebrae was 7.03 ± 0.80, and the average number of fixed pedicle screws was 12.54 ± 1.32. Implant density was calculated as 1.80 ± 0.17. For the UIV, T8 was included in 1 case, T9 was included in 12 cases, T10 was included in 16 cases, and T11 was included in 8 cases; for the LIV, L3 was included in 10 cases, L4 was included in 23 cases, and L5 was included in 4 cases. Regarding the clinical outcomes, the average operative time was 175.84 ± 42.04 minutes, and the mean intraoperative blood loss was 606.35 ± 220.03 mL. At the final follow-up, the average thoracic final correction rate was 38.4 ± 16.5%, while the lumbar final correction rate (%) reached 70% (Table 1).

## Radiographical Data

*Coronal Plane Parameters.* The average preoperative Cobb angles of the thoracic and TL/L curves were 24.0 ± 9.0° and 45.4 ± 6.3°, respectively (Table 2). Three months after surgery, the Cobb angles of the 2 curves corrected to 12.2 ± 6.5° and 12.4 ± 4.7°, respectively, which were significantly different from the preoperative angles. According to repeated-measures analysis of variance, a significant change was found in the main thoracic curve but not the TL/L curve preoperatively to postoperatively, while the pairwise comparison indicated no statistical significance. As shown in Figure 2, the main thoracic curve presented an increasing trend postoperatively, but the change was not statistically significant.

The coronal TS values were 17.1 ± 7.9 mm preoperatively, 8.6 ± 3.9 mm at the 3-month follow-up, and 9.9 ± 3.2 mm at the final follow-up. No statistically significant difference was identified in the subsequent postoperative visits. Nevertheless, coronal balance significantly improved at the 3-month follow-up ($P < .001$) and remained relatively constant in the subsequent postoperative period. For the apical vertebral translation (AVT), the statistical results showed large differences postoperatively in both the thoracic and lumbar regions. As shown in the linear chart in Figure 2, there was a slight increasing tendency both in the thoracic AVT and TL/L AVT, which was consistent with the repeated measurement analysis of variance results, while the pairwise comparison showed no significant differences from before to after the surgery. The shoulder height difference was 13.2 ± 6.8 mm preoperatively and significantly improved postoperatively.

To further study the restoration of coronal balance, subgroup analysis was performed according to whether the preoperative C7-CSVL was larger than 20 mm. As shown in Table 3, there was no significant difference in the preoperative radiographic parameters, except for TS and C7-CSVL. At the 3-month follow-up, the coronal balance was restored in all the patients in the imbalanced group, with the C7-CSVL being slightly larger than that in the balanced group ($P = .004$). At the final visit, no difference was found between the 2 groups in the C7-CSVL ($P = .497$). However, TJK was significantly

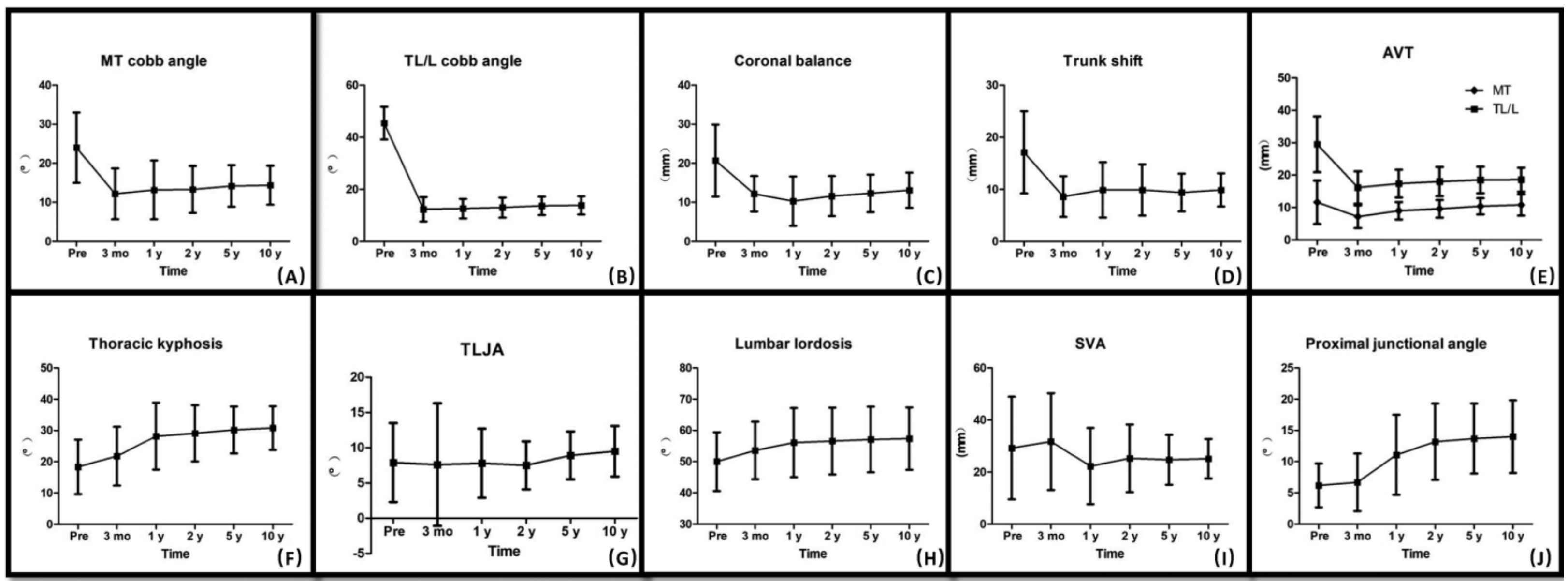


**Figure 2.** Liner chart presentations of preoperative and postoperative long-term follow-ups' results of various radiological parameters: (A) main thoracic cobb angle; (B) thoracolumbar/lumbar cobb angle; (C) coronal balance (C7-CSVL); (D) trunk shift; (E) main thoracic and TL/L apical vertebrae translation (AVT); (F) thoracic kyphosis; (G) thoracolumbar junctional angle (TJLA); (H) lumbar lordosis; (I) sagittal vertical axis (SVA); (J) proximal junctional angle.

**Table 3.** Comparisons of Radiological Parameters Between Imbalance Group and Balance Group.

| | Preoperation | | | Postoperation (3 months) | | | Final follow-up | | |
|---|---|---|---|---|---|---|---|---|---|
| | Imbalance group (N = 20) | Balance group (N = 17) | *P* value | Imbalance group (N = 20) | Balance group (N = 17) | *P* value | Imbalance group (N = 20) | Balance group (N = 17) | *P* value |
| Coronal plane | | | | | | | | | |
| MT | 24.4 ± 9.6 | 23.3 ± 8.3 | .690 | 12.2 ± 6.9 | 12.9 ± 6.6 | .720 | 14.5 ± 5.0 | 14.4 ± 5.1 | .946 |
| TL/L | 46.7 ± 7.8 | 43.8 ± 3.4 | .145 | 14.2 ± 5.2 | 9.9 ± 2.9 | **.004** | 14.8 ± 2.7 | 12.4 ± 4.3 | **.049** |
| AVT (T) | 12.3 ± 6.2 | 11.1 ± 7.2 | .605 | 6.5 ± 3.0 | 8.8 ± 5.4 | .113 | 11.1 ± 3.1 | 11.3 ± 4.8 | .892 |
| AVT (TL/L) | 28.0 ± 7.4 | 31.6 ± 9.4 | .190 | 16.1 ± 5.0 | 16.3 ± 4.9 | .913 | 18.4 ± 2.5 | 18.3 ± 5.2 | .990 |
| RSH | 12.4 ± 5.6 | 13.4 ± 7.2 | .298 | 8.7 ± 3.8 | 7.6 ± 3.9 | .365 | 7.7 ± 2.4 | 7.9 ± 4.2 | .864 |
| TS | 20.9 ± 7.8 | 12.1 ± 5.8 | **<.001** | 9.5 ± 3.8 | 8.2 ± 4.6 | .378 | 10.1 ± 3.6 | 9.7 ± 2.8 | .721 |
| CB | 27.7 ± 5.7 | 12.3 ± 4.2 | **<.001** | 14.9 ± 3.7 | 10.2 ± 5.6 | **.004** | 13.0 ± 4.7 | 14.0 ± 5.2 | .497 |
| Sagittal plane | | | | | | | | | |
| TK | 18.6 ± 9.6 | 17.3 ± 8.4 | .668 | 22.6 ± 9.0 | 20.5 ± 9.8 | .505 | 30.8 ± 5.4 | 32.9 ± 11.9 | .484 |
| TJLA | 8.9 ± 5.9 | 7.6 ± 6.0 | .508 | 5.4 ± 5.4 | 9.8 ± 10.9 | .119 | 8.4 ± 3.7 | 10.8 ± 2.9 | **.029** |
| LL | 50.6 ± 9.0 | 49.0 ± 9.8 | .604 | 54.4 ± 9.3 | 51.1 ± 11.2 | .329 | 59.5 ± 11.9 | 53.9 ± 7.9 | .103 |
| SVA | 32.6 ± 21.2 | 23.9 ± 17.9 | .185 | 32.7 ± 16.6 | 30.1 ± 20.6 | .671 | 24.3 ± 6.6 | 25.7 ± 8.6 | .557 |
| PJA | 6.3 ± 4.1 | 6.1 ± 2.9 | .867 | 6.8 ± 4.6 | 6.4 ± 4.6 | .840 | 14.3 ± 5.7 | 15.8 ± 11.0 | .574 |

Abbreviations: TL/L, thoracolumbar/lumbar; AVT, apical vertebrae translation; RSH, radiographic shoulder height; TS, trunk shift; TK, thoracic kyphosis; TJLA, thoracolumbar junctional angle; LL, lumbar lordosis; SVA, sagittal vertical axis; PJA, proximal junctional angle; MT, main thoracic, CB, coronal balance.
The values in boldface means the difference was statistically significant.

**Table 4.** Comparisons of Radiological Parameters Between M Group and N Group According to Lenke Sagittal Modifier.

| | Preoperation | | | Postoperation (3 month) | | | Final follow-up | | |
|---|---|---|---|---|---|---|---|---|---|
| | N group (N = 29) | M group (N = 8) | *P* value | N group (N = 29) | M group (N = 8) | *P* value | N group (N = 29) | M group (N = 8) | *P* value |
| Coronal plane | | | | | | | | | |
| MT | 23.1 ± 9.3 | 24.2 ± 9.1 | .769 | 10.3 ± 6.0 | 12.8 ± 6.6 | .340 | 14.9 ± 3.8 | 14.3 ± 5.4 | .769 |
| TL/L | 45.5 ± 6.0 | 45.4 ± 6.4 | .962 | 10.4 ± 1.8 | 12.9 ± 5.1 | .181 | 14.6 ± 1.3 | 13.7 ± 3.8 | .262 |
| AVT (T) | 9.4 ± 4.5 | 12.2 ± 7.1 | .296 | 6.6 ± 2.0 | 7.3 ± 3.8 | .649 | 11.8 ± 3.3 | 10.6 ± 3.2 | .364 |
| AVT (TL/L) | 29.0 ± 5.7 | 29.7 ± 9.3 | .807 | 14.9 ± 2.6 | 16.6 ± 5.4 | .396 | 18.9 ± 1.5 | 18.5 ± 4.2 | .797 |
| RSH | 12.4 ± 5.6 | 13.4 ± 7.2 | .698 | 9.0 ± 3.1 | 8.1 ± 4.0 | .801 | 8.5 ± 2.2 | 7.8 ± 3.4 | .602 |
| TS | 16.1 ± 5.6 | 17.3 ± 8.5 | .714 | 8.1 ± 2.9 | 8.7 ± 4.2 | .708 | 8.4 ± 2.5 | 10.3 ± 3.3 | .141 |
| CB | 21.9 ± 8.1 | 20.4 ± 9.6 | .689 | 13.0 ± 4.8 | 12.0 ± 4.5 | .583 | 16.5 ± 4.0 | 12.2 ± 4.3 | **.015** |
| Sagittal plane | | | | | | | | | |
| TK | 5.9 ± 1.7 | 21.8 ± 6.4 | **<.001** | 11.4 ± 7.0 | 24.6 ± 7.8 | **<.001** | 24.5 ± 5.9 | 32.6 ± 6.2 | **.002** |
| TJLA | 6.9 ± 4.3 | 8.2 ± 5.9 | .569 | 9.6 ± 16.5 | 7.0 ± 5.2 | .675 | 9.4 ± 2.2 | 9.5 ± 3.9 | .945 |
| LL | 45.3 ± 8.5 | 51.3 ± 9.3 | .105 | 55.6 ± 9.1 | 53.0 ± 9.3 | .481 | 56.4 ± 7.2 | 57.7 ± 10.8 | .754 |
| SVA | 22.6 ± 19.3 | 31.0 ± 19.8 | .300 | 33.8 ± 22.7 | 31.1 ± 17.8 | .724 | 21.5 ± 6.0 | 26.0 ± 7.8 | .140 |
| PJA | 6.3 ± 3.6 | 6.2 ± 3.6 | .976 | 3.8 ± 2.0 | 7.5 ± 4.8 | **.003** | 11.8 ± 6.0 | 14.6 ± 5.7 | .224 |

Abbreviations: N group, normal group; M group, minus group; TL/L, thoracolumbar/lumbar; AVT, apical vertebrae translation; RSH, radiographic shoulder height; TS, trunk shift; TK, thoracic kyphosis; TJLA, thoracolumbar junctional angle; LL, lumbar lordosis; SVA, sagittal vertical axis; PJA, proximal junctional angle; MT, main thoracic, CB, coronal balance.
The values in boldface means the difference was statistically significant.

different between the 2 groups at the final visit (8.4 ± 3.7 vs 10.8 ± 2.9, $P = .029$). Otherwise, the instrumented TL/L curve was larger in the imbalanced group than in the balanced group at the 3-month follow-up (14.2 ± 5.2 vs 9.9 ± 2.9, $P = .004$) and at the final visit (14.8 ± 2.7 vs 12.4 ± 4.3, $P = .049$).

*Sagittal Plane Parameters.* There was no significant change in the TJLA or LL between the preoperative and first visits ($P > .10$) or between any of the subsequent postoperative visits ($P > .05$). For TK and the PJA, large and significant differences were found among the postoperative follow-ups ($P < .001$). Pairwise comparisons showed large significant differences at 3 months and 1 year postoperatively in TK ($P = .002$), and the changes during the remaining postoperative period were not significant ($P > .10$). As shown in the linear chart in Figure 2, there was an increasing tendency of TK, and this trend seemed to taper after the 1-year follow-up. For the PJA, there was no significant difference between the preoperative and first postoperative visits ($P = .769$), but the angle gradually increased from 6.7 ± 4.6° to 13.7 ± 5.6° in the following 5 years. The

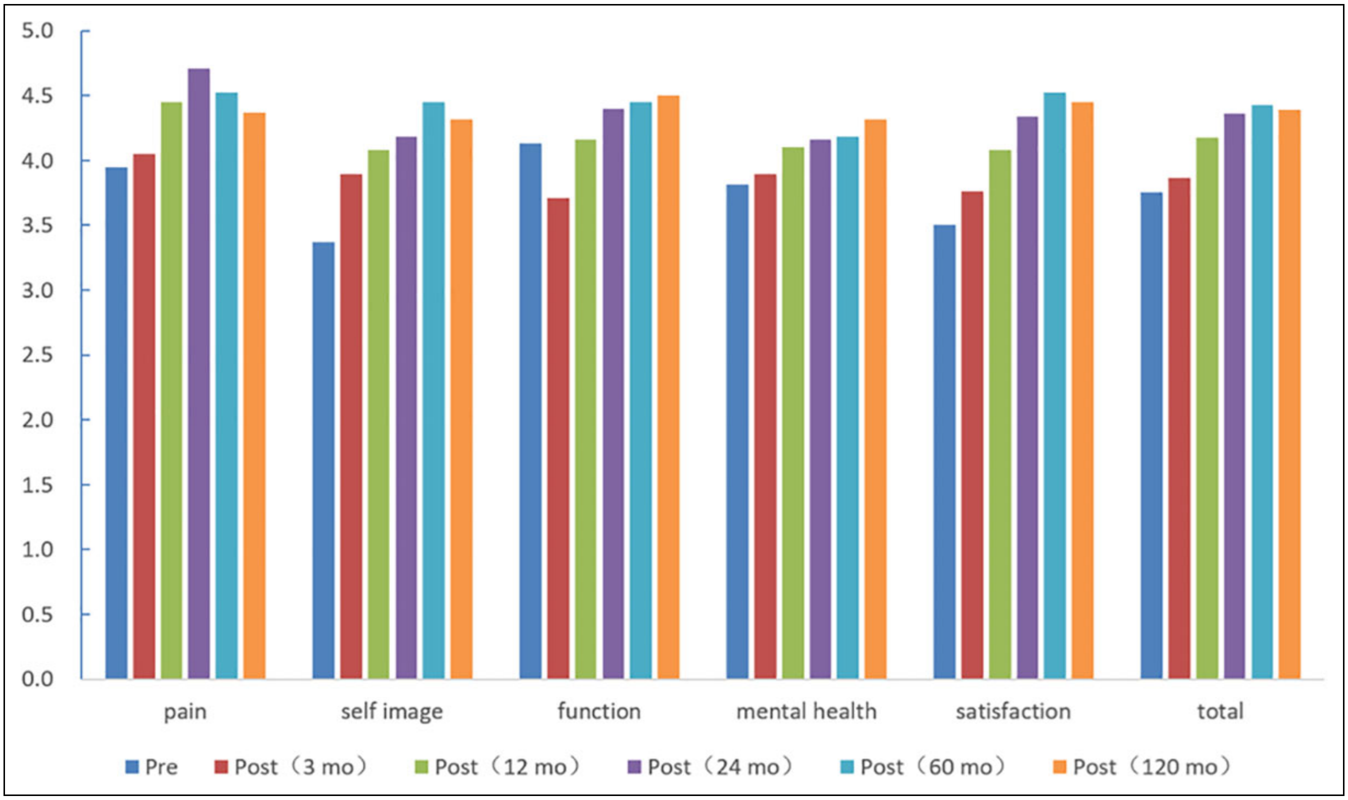


**Figure 3.** Distribution of preoperative and postoperative long-term follow-ups' score results in each domain of SRS-22.

linear chart shows that this increasing tendency tapered at the 2-year follow-up. Moreover, a large significant difference was found in the SVA between 3 months and 1 year postoperatively (31.7 $\pm$ 18.6 vs 22.3 $\pm$ 14.6, $P = .006$).

Both the normal kyphosis (N) group and minus (M) group showed good correction in the coronal and sagittal alignment (Table 4). No significant differences were found in the preoperative radiographic parameters, except for TK. Nevertheless, the TJLA, LL, and SVA were slightly larger in the M group than in the N group at the final follow-up. At the 3-month follow-up, the degree of TK remained larger in the M group, and there was a significant difference in the PJA between groups (3.8 $\pm$ 2.0 vs 7.5 $\pm$ 4.8, $P = .003$). However, the difference in PJA disappeared, while the difference in TK remained. Moreover, the C7-CSVL was significantly different between the 2 groups at the final visit (16.5 $\pm$ 4.0 vs 12.2 $\pm$ 4.3, $P = .015$).

### Clinical Outcomes

From the preoperative visit to the final visit, the SRS-22 total scores improved significantly. In addition, large improvements were observed in all domains (Figure 3). The scores for the pain, self-image, and satisfaction domains were slightly lower at the final visit than at the 5-year follow-up.

Of all 37 patients, 2 patients had superficial infections at the operative wound. With wound dressing changes and antibacterial therapy, they recovered. However, no other complications were reported intraoperatively or during the follow-up period, such as deep wound infections, intraoperative monitoring loss, paralysis, pseudarthrosis, or revision surgeries.

## Discussion

The goal of surgery for AIS is to obtain a well-balanced spine, maximal functionality of the spine and better correction of the curvature.[11,12] In addition, to decrease the amount of damage incurred by patients and reduce the financial burden on patients' families,[13,14] the concept of selective fusion in surgery to treat spinal deformities has been gradually accepted. With the advent of the Lenke classification, selective TL/L fusion for Lenke 5C AIS attracted spine surgeons' attention, as it can reduce the number of fused levels, maximize spinal flexibility and distribute stress across more distal lumbar motion segments than can traditional TL/L fusion.[1] An enormous amount of research has been performed to validate the efficiency and outcomes of selective TL/L fusion.[1,10,15-23]

### Analysis in the Coronal Plane

The unfused thoracic curvature underwent 2 processes: immediate spontaneous correction after surgery and gradually spontaneous correction during the follow-up period when the fused TL/L curve was relatively stable. Bennett et al[24] analyzed the radiographic and clinical outcomes of patients who underwent TL/L curve fusion with posterior pedicle screws at a 5-year

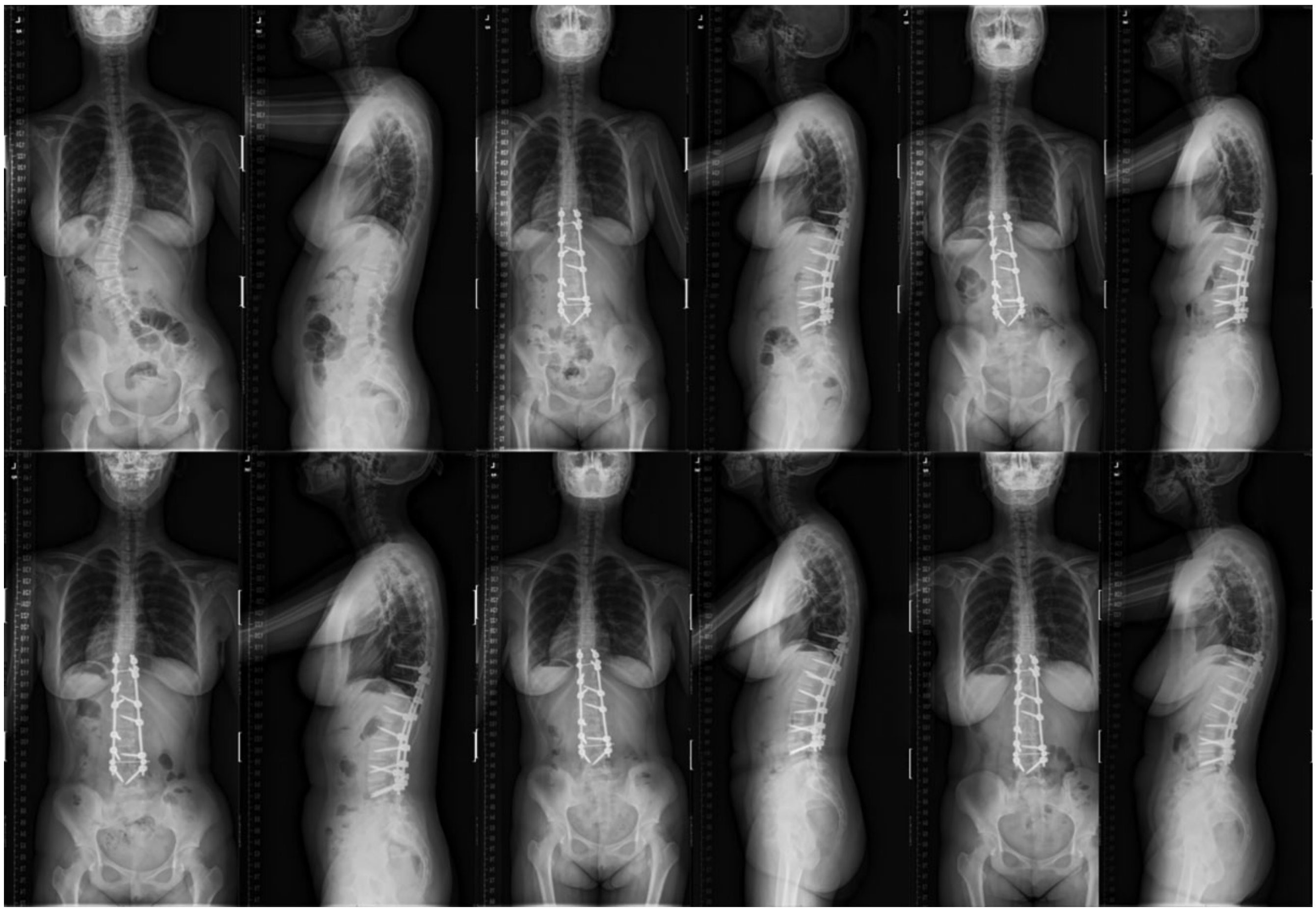

**Figure 4.** A female patient with Lenke sagittal normal modifier (TK = 21°) who underwent selective TL/L fusion at age of 14 (Risser 3) and demonstrated great global balance that was maintained at 10 years.

follow-up. The authors reported that both curves remained stable from the first postoperative radiographs to the 5-year follow-up radiographs after selective TL/L fusion. Zhang et al[21] found that the TL/L curve corrected to 6° immediately and changed to 9° at the final follow-up with a correction loss of 3°. Moreover, the thoracic curve spontaneously corrected to 13° immediately and changed to 14° at the final follow-up with a correction loss of 1°. A meta-analysis[3] determined that the average TL/L curve was 40° to 58° preoperatively corrected to 4° to 15° at the immediate postoperative follow-up, with a correction rate of 71% to 91%, and changed to 4° to 19° at the final follow-up, with a correction rate of 55% to 94%, after posterior selective TL/L fusion. Moreover, the average thoracic curve was 23° to 31° preoperatively and spontaneously corrected to 10° to 22° at the immediate postoperative follow-up, with a correction rate of 19% to 61%, and then changed to 9° to 20° at the final follow-up, with a correction rate of 19% to 67%. Various scholars have reached a consensus that posterior selective TL/L fusion can lead to uninstrumented compensatory thoracic curves adjusting to match the instrumented primary curve and that these compensatory curves do not seem to progress during the follow-up period.[15,16,25] However, long-term radiographical and clinical outcomes have not been reported in the literature. In our study, we observed that the primary TL/L curve corrected to 12.4° at the 3-month follow-up postoperatively, with a correction loss of 1.5° at the 10-year follow-up, while the thoracic curve spontaneously corrected to 12.2° at the 3-month follow-up, only with a correction loss of 2.2° at the 10-year follow-up. So, the increasing trend in the thoracic curve was not obvious, although the statistical results indicated a difference among the follow-ups (Figure 2). Therefore, it can be considered that posterior selective TL/L fusion can effectively correct spinal deformities and yield long-term stability.

Preoperative coronal spinal imbalance is common in Lenke 5 AIS patients.[26] Yoshihara et al[3] reviewed 50 studies on Lenke 5 AIS and concluded that the average preoperative coronal alignment was imbalanced. In their research, 29 studies showed the average postoperative coronal alignment was balanced, and 13 studies showed the coronal alignment was imbalanced. At the final follow-up, the average coronal alignment was within normal limits in all the reported studies, except for one study group including coronal imbalanced patients.[7] In the current study, 20 out of 37 patients showed

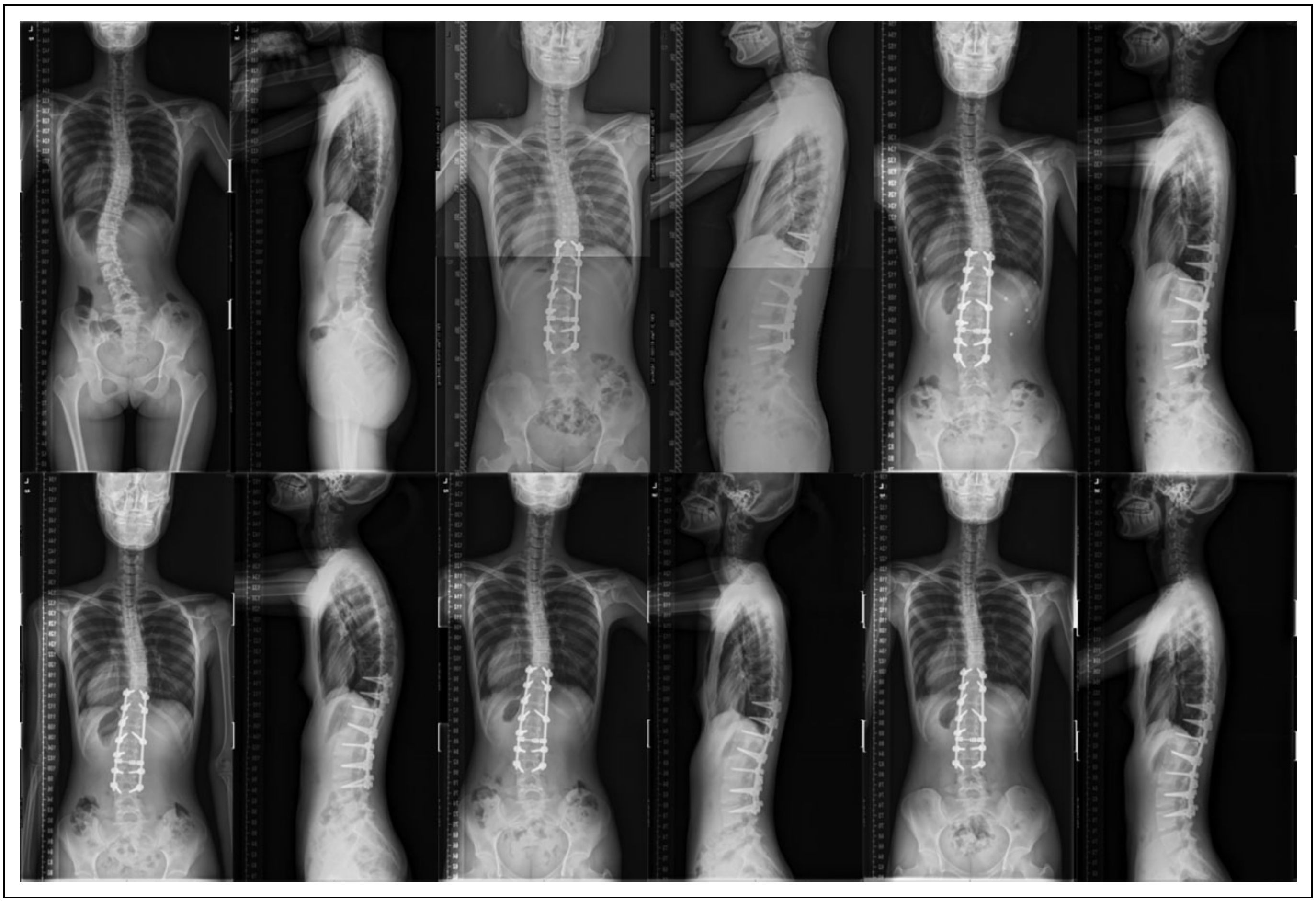

**Figure 5.** A female patient with Lenke sagittal minus modifier (TK = 7°) who underwent selective TL/L fusion at age of 14 (Risser 4) and demonstrated great global balance that was maintained at 10 years.

preoperative coronal imbalance, and most of the cases were restored to normal levels at the 3-month follow-up and maintained this state during the following period. To further analyze this phenomenon, we divided the patients into a coronal balanced group and an imbalanced group according to whether the preoperative magnitude of coronary misalignment (C7-CSVL) exceeded 20 mm.[27] After arthrodesis, the coronal imbalanced group exhibited a larger TL/L curve than did the coronal balanced group until the final visit. Moreover, the TJLA was larger in the coronal balanced group at the final follow-up. Hwang et al[28] considered that larger thoracolumbar kyphosis and a larger distal junctional angle preoperatively were predictive factors for immediate coronal imbalance in Lenke 5C curves. Chen et al[29] found that a smaller postoperative TL/L Cobb angle was the primary risk factor for immediate coronal imbalance in Lenke 5 and 6 AIS patients. However, the outcomes of these studies were inconsistent. These differences may be caused by several reasons. First, the coronal imbalance phenomenon was caused by various factors. In addition to the above possible factors, the flexibility of thoracic and lumbar curves and LIV tilt were also accepted as factors that can account for this decompensation. Second, scholars have found that coronal imbalance often occurs in the early postoperative period[16,29,30] (immediately after the operation). However, our first follow-up was conducted 3 months postoperatively, and the coronal imbalance that occurred immediately postoperatively was nearly fully corrected spontaneously. Third, the difference in inclusion criteria and operative methods may also be important reasons for the changes in coronal balance.

## *Analysis in the Sagittal Plane*

As surgical techniques and instrumentation have evolved, researchers have paid more attention to the sagittal plane for optimal correction than the coronal plane. It is of great importance for patients that normal sagittal alignment is restored because it affects the quality of life of the patients.[7,17,18] Unlike adult spinal deformities, most AIS patients have a normal SVA (SVA $< 50$ mm). The mean SVA was 29.2 $\pm$ 19.7 mm preoperatively, and it changed to 25.1 $\pm$ 7.6 mm at the final follow-up in our study. Moreover, we found that the degree of TK increased after posterior selective TL/L fusion in many studies.[17,18,21,22,31] In our study, there was a significant difference in TK between the preoperative and 3-month follow-up X-rays.

In addition, the linear chart showed an increasing trend in TK, which remained almost constant after the 1-year follow-up. Nevertheless, the variation in the PJA was highly significant across the postoperative period, and its increasing trend tapered to the 2-year follow-up. Our research group also proposed the concept of sagittal spontaneous correction in the thoracic area after selective TL/L fusion. Therefore, a more detailed distribution was conducted according to the Lenke sagittal modifiers.[4] Eight patients were included in the Lenke sagittal modifier minus group (M group), while 29 patients were included in the normal group (N group). Except for TK ($P < .001$), no large differences were found in the perioperative radiographical parameters. Nevertheless, there was still a large and significant difference in TK from before to after the operation, and we found that the variation in TK in the M group became more similar to that in the N group, which might be a result of self-normalization after posterior surgery. Moreover, a significant difference between groups was found in the PJA at the 3-month follow-up, and a larger PJA was observed in the M group than in the N group at the final visit. Additionally, compared with the N group, the M group showed improved coronal balance at the final follow-up (16.5 $\pm$ 4.0 vs 12.2 $\pm$ 4.3, $P = .015$). In the posterior correction procedure, the uninstrumented sagittal compensatory curves adjusted to match the instrumented primary curve. Tauchi et al[18] reported that selective TL/L correction was more likely to affect the M group than the N group in the restoration of sagittal alignment, and we found similar outcomes in our study. Typical images of patients in the N group and M group are shown in Figure 4 and Figure 5, respectively.

PJK of thoracolumbar region was well evaluated in adult scoliosis, but not in AIS patients. Many literatures only reported the rate of PJK in the thoracic region of AIS patients.[32-34] However, it is lack of report on the incidence of PJK in the thoracolumbar region after posterior selective TL/L curve correction with long time follow-up. PJK occurred in 1 out of 37 patients at 3 months postoperation, while 12 out of 37 patients with an incidence of 32.4% at 10 years follow-up in our study. With the extension of follow-up time, the number of PJK is increased, which may result from PJA increase during the follow-up. However, there were no significant different rate of PJK between group M and group N, between imbalance group and balance group at 3 months and 10 years postoperation. At present, there is no unified opinion on the risk factors of PJK.[34] Therefore, we speculated that PJK remained a multifactorial problem and a dynamic compensatory mechanism, which coordinated to maintain the balance of human body for a minimization of energy expense in walking or standing position.

### Limitations

Given the paucity of Lenke 5C curves in AIS patients, our study had some limitations. First, this was a retrospective study, which may affect the strength of the conclusions. Second, the number of patients included in this study was relatively small due to the long follow-up period. Third, the aim of our study was to report the long-term outcomes of posterior selective TL/L fusion in Lenke type 5C AIS patients; however, a more detailed analysis and comparative interpretation were not performed to reveal the risk factors, which should be performed in the future. Nonetheless, a multicentric study with a larger sample size is needed to further validate our findings.

## Conclusion

Posterior selective TL/L fusion yielded favorable outcomes at the long-term follow-up in Lenke type 5C AIS patients. TK and LL were coordinated and remained unchanged after the 1-year follow-up. The variation in the PJA was highly significant in the postoperative period, and it showed an increasing trend until the 2-year follow-up. The SRS-22 scores improved from the preoperative visit to the 10-year follow-up visit.

### Ethical Approval

This study was approved by the ethics committee of our university (Local Ethics Committee of Changhai Hospital, SMMU, No. CHEC20160183).

### Informed Consent

All subjects in our study provided written informed consent for the study.

### Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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### References

1. Lenke LG, Edwards CC 2nd, Bridwell KH. The Lenke classification of adolescent idiopathic scoliosis: how it organizes curve patterns as a template to perform selective fusions of the spine. *Spine (Phila Pa 1976)*. 2003;28:S199-S207.
2. Esposito VR, Dial BL, Fitch RD, Lark RK. Periapical wires result in less curve correction than pedicle screw constructs in idiopathic scoliosis. *Asian Spine J*. 2019;13:1010-1016.
3. Yoshihara H. Surgical treatment of Lenke type 5 adolescent idiopathic scoliosis: a systematic review. *Spine (Phila Pa 1976)*. 2019;44:E788-E799.
4. Lenke LG, Betz RR, Harms J, et al. Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis. *J Bone Joint Surg Am*. 2001;83:1169-1181.

5. Chang DG, Suk SI, Song KS, et al. How to avoid distal adding-on phenomenon for rigid curves in major thoracolumbar and lumbar adolescent idiopathic scoliosis? Identifying the incidence of distal adding-on by selection of lowest instrumented vertebra. *World Neurosurg*. 2019;132:e472-e478.
6. Qin X, Xia C, Xu L, et al. Natural history of postoperative adding-on in adolescent idiopathic scoliosis: what are the risk factors for progressive adding-on? *Biomed Res Int*. 2018;2018:3247010.
7. Yang X, Hu B, Song Y, et al. Coronal and sagittal balance in Lenke 5 AIS patients following posterior fusion: important role of the lowest instrument vertebrae selection. *BMC Musculoskelet Disord*. 2018;19:212.
8. Sinagra Z, Cunningham G, Dillon D, Woodland P, Baddour E. Proximal junctional kyphosis and rates of fusion following posterior instrumentation and spinal fusion for adolescent idiopathic scoliosis. *ANZ J Surg*. 2020;90:597-601.
9. Pasha S, Baldwin K. Surgical outcome differences between the 3D subtypes of right thoracic adolescent idiopathic scoliosis. *Eur Spine J*. 2019;28:3076-3084.
10. Louer C Jr, Yaszay B, Cross M, et al. Ten-year outcomes of selective fusions for adolescent idiopathic scoliosis. *J Bone Joint Surg Am*. 2019;101:761-770.
11. Hresko MT.Clinical practice. Idiopathic scoliosis in adolescents. *N Engl J Med*. 2013;368:834-841.
12. Yaman O, Dalbayrak S. Idiopathic scoliosis. *Turk Neurosurg*. 2014;24:646-657.
13. Muhly WT, Sankar WN, Ryan K, et al. Rapid recovery pathway after spinal fusion for idiopathic scoliosis. *Pediatrics*. 2016;137: 20151568.
14. Bozzio AE, Hu X, Lieberman IH. Cost and clinical outcome of adolescent idiopathic scoliosis surgeries—experience from a nonprofit community hospital. *Int J Spine Surg*. 2019;13:474-478.
15. Senkoylu A, Luk KDK, Wong YW, Cheung KM. 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.
16. Hwang CJ, Lee CS, Kim H, Lee DH, Cho JH. Spontaneous correction of coronal imbalance after selective thoracolumbar-lumbar fusion in patients with Lenke-5C adolescent idiopathic scoliosis. *Spine J*. 2018;18:1822-1828.
17. Protopsaltis T, Bronsard N, Soroceanu A, et al. Cervical sagittal deformity develops after PJK in adult thoracolumbar deformity correction: radiographic analysis utilizing a novel global sagittal angular parameter, the CTPA. *Eur Spine J*. 2017;26:1111-1120.
18. Tauchi R, Kawakami N, Ohara T, et al. Sagittal alignment profile following selective thoracolumbar/lumbar fusion in patients with Lenke type 5C adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)*. 2019;44:1193-1200.
19. Ilgenfritz RM, Yaszay B, Bastrom TP, Newton PO; Harms Study Group. Lenke 1C and 5C spinal deformities fused selectively: 5-year outcomes of the uninstrumented compensatory curves. *Spine (Phila Pa 1976)*. 2013;38:650-658.
20. Dong Y, Weng X, Zhao H, Zhang J, Shen J, Qiu G. Lenke 5C curves in adolescent idiopathic scoliosis: anterior vs posterior selective fusion. *Neurosurgery*. 2016;78:324-331.
21. Zhang Y, Lin G, Zhang J, et al. Radiographic evaluation of posterior selective thoracolumbar or lumbar fusion for moderate Lenke 5C curves. *Arch Orthop Trauma Surg*. 2017;137:1-8.
22. 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.
23. Sun Z, Qiu G, Zhao Y, et al. The effect of unfused segments in coronal balance reconstitution after posterior selective thoracolumbar/lumbar fusion in adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)*. 2014;39:2042-2048.
24. Bennett JT, Hoashi JS, Ames RJ, Kimball JS, Pahys JM, Samdani AF. The posterior pedicle screw construct: 5-year results for thoracolumbar and lumbar curves. *J Neurosurg Spine*. 2013;19: 658-663.
25. Zhang Y, Lin G, Wang S, et al. Higher flexibility and better immediate spontaneous correction may not gain better results for nonstructural thoracic curve in Lenke 5C AIS patients: risk factors for its correction loss. *Spine (Phila Pa 1976)*. 2016;41:1731-1739.
26. Abel MF, Singla A, Feger MA, Sauer LD, Novicoff W. Surgical treatment of Lenke 5 adolescent idiopathic scoliosis: comparison of anterior vs posterior approach. *World J Orthop*. 2016;7: 553-560.
27. Wang Y, Bunger CE, Zhang Y, et al. Lowest instrumented vertebra selection for Lenke 5C scoliosis: a minimum 2-year radiographical follow-up. *Spine (Phila Pa 1976)*. 2013;38: E894-E900.
28. Hwang SW, Pahys JM, Bastrom TP, Lonner BS, Newton PO, Samdani AF. Lower SRS mental health scores are associated with greater preoperative pain in patients with adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)*. 2019;44:1647-1652.
29. Chen K, Bai J, Yang Y, et al. Immediate postoperative coronal imbalance in Lenke 5 and Lenke 6 adolescent idiopathic scoliosis: is it predictable? *Eur Spine J*. 2019;28:2042-2052.
30. Shetty AP, Suresh S, Aiyer SN, Kanna R, Rajasekaran S. Radiological factors affecting post-operative global coronal balance in Lenke 5C scoliosis. *J Spine Surg*. 2017;3:541-547.
31. Ketenci IE, Yanik HS, Ulusoy A, Demiroz S, Erdem S. Lowest instrumented vertebrae selection for posterior fusion of Lenke 5C adolescent idiopathic scoliosis: can we stop the fusion one level proximal to lower-end vertebra? *Indian J Orthop*. 2018;52:657-664.
32. Bjerke BT, Zarrabian M, Aleem IS, et al. Incidence of osteoporosis-related complications following posterior lumbar fusion. *Global Spine J*. 2018;8:563-569.
33. Iyer S, Kim HJ, Theologis A, et al. Outcomes of fusions from the cervical spine to the pelvis. *Global Spine J*. 2019;9:6-13.
34. Kim JS, Phan K, Cheung ZB, et al. Surgical, radiographic, and patient-related risk factors for proximal junctional kyphosis: a meta-analysis. *Global Spine J*. 2019;9:32-40.