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ORIGINAL ARTICLE

Risk factors of proximal junctional angle increase after selective posterior thoracolumbar/lumbar fusion in patients with adolescent idiopathic scoliosis

Zhijian Sun · Guixing Qiu · Yu Zhao · Shigong Guo · Yipeng Wang · Jianguo Zhang · Jianxiong Shen

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Abstract
Purpose To analyze risk factors for an increase in proximal junctional angle (PJA) after posterior selective thoracolumbar/lumbar (TL/L) curve fusion in patients with adolescent idiopathic scoliosis (AIS).
Methods AIS patients that underwent selective posterior TL/L curve fusion with a minimum of 2-year follow-up were identified. Demographic and radiographic data were collected before surgery, at first erect after surgery and at final follow-up. Multiple linear regression analysis was performed to determine the relation of PJA changes during follow-up and eight potential risk factors, including locations of upper instrumented vertebra (UIV), locations of lower instrumented vertebra (LIV), length of fusion segments, types of pedicle screw alignment, lumbar lordosis (LL) at first erect after surgery, LL changes before and after surgery, sagittal vertical axis (SVA) at first erect after surgery and SVA changes before and after surgery.
Results A total of 41 patients were included in this study. There were 37 female and 4 male with a mean age of 14.7 years at surgery. PJA was increased from 5.5° immediately after surgery to 10.8° at the last follow-up ($P < 0.0001$). Regression analysis showed that locations of LIV, LL changes before and after surgery and SVA changes before and after surgery were risk factors for increased PJA. Pearson correlation test showed that postoperative LIV inclination was significantly correlated with PJA changes.
Conclusions Location of LIV above or equal to L3, higher postoperative LL and deteriorative negative SVA with surgery were potential risk factors for increased PJA during follow-up. Postoperative LIV inclination more than 5°might be also an indicator for an increase in PJA.

Keywords Adolescent idiopathic scoliosis · Thoracolumbar/lumbar curve · Proximal junctional angle · Proximal junctional kyphosis · Risk factors

Introduction

Proximal junctional kyphosis (PJK), an abnormal kyphotic deformity involving spinal segments proximally adjacent to the fusion segments, was a common complication after spinal deformity surgeries. According to Kim's systematic review, the incidence of PJK ranged from 17 to 39 % among heterogeneous populations based on varying definitions of PJK [1]. Severe PJK would cause regional pain [2, 3], diminish patients' self-image evaluation [4] and ultimately lead to revision surgery in some cases [5, 6]. Many risk factors had been identified by different groups of surgeons [2, 4, 7–16]. These risk factors were concluded from both adult and adolescent spinal deformities.

Among them, several studies had focused on patients with adolescent idiopathic scoliosis (AIS) [7, 8, 10–12, 17]. Various risk factors were identified, including thoracoplasty, preoperative hyperkyphotic thoracic alignment (T5–T12 > 40°), hybrid instrumentation, greater immediate postoperative thoracic kyphosis (TK) angle decrease, male sex, pedicle screw constructs including constructs at the top

Z. Sun · G. Qiu · Y. Zhao (✉) · Y. Wang · J. Zhang · J. Shen
Department of Orthopaedics, Peking Union Medical College Hospital, Chinese Academy of Medical Sciences and Peking Union Medical College, Dongcheng District Shuaifuyuan No.1, Beijing 100730, China
e-mail: zhaoyupumch@163.com

S. Guo
Department of Trauma and Orthopaedic Surgery, Lister Hospital, Stevenage, UK

vertebra, autogenous bone graft and fusion to the lower lumbar vertebra (below L2) [7, 10–12]. However, it should be noted that these studies had focused on PJK of proximal thoracic region as the upper instrumented vertebra (UIV) was located at upper or middle thoracic segments in all [8, 12] or most [7, 10, 11, 17] of the patients in these studies.

Thoracolumbar/lumbar (TL/L) idiopathic scoliosis is a special type of scoliosis, characterized as having main TL/L curves and minor thoracic curves. Normally, selective fusion of TL/L curve could achieve satisfactory correction results when the minor thoracic curves were nonstructural based on the Lenke and PUMC classifications [18, 19], in which case, most of the lumbar segments would be fused and most thoracic segments left unfused. Thus, the sagittal alignment changes after surgery might be different from other types of idiopathic scoliosis.

In the current literature, there has not been any study analyzing the risk factors for proximal junctional angle (PJA) changes of the thoracolumbar region following selective posterior TL/L curve fusion for AIS. Therefore, the purpose of our study was to use multiple linear regression analysis to investigate these risk factors for PJA changes to further our understanding of the development of PJK and to provide a useful point of reference for surgical planning in the clinical setting.

Materials and methods

Subjects

After approval from the institution review board of our hospital, the radiographs of all AIS patients that received surgical treatment in our hospital were retrospectively reviewed. Patients who met all of the following criteria were included: (1) patients with diagnosis of AIS and age $\leq$20 years; (2) patients with major TL/L curves that underwent one stage selective posterior fusion surgery with all pedicle screws; (3) the UIV below T8; (4) patients with a minimum of 2-year follow-up; (5) no previous spine surgery.

Demographic data collection and radiographic measurements

Descriptive data of included patients were collected, including age, sex, follow-up period and scoliosis classification. Surgically related data, including UIV, lower instrumented vertebra (LIV), ranges of fusion segments and types of pedicle screw alignment, were also collected.

Measurements were made on standing posteroanterior and lateral radiographs before surgery, first erect after surgery and at the last follow-up, as well as preoperative supine bending radiographs. Cobb angles of major TL/L curve and minor thoracic curve were measured on posteroanterior and reverse bending images. On the lateral radiographs, global sagittal balance was measured in millimeters as the distance from the C7 plumbline to the perpendicular line from the posterior-superior corner of S1 (sagittal vertical axis, SVA). If the C7 plumbline was posterior to the posterior-superior corner of S1, SVA was defined as negative (negative sagittal balance). If the C7 plumbline intersected through the posterior-superior corner of S1, SVA was zero (neutral balance). If the C7 plumbline was anterior to the posterior-superior corner of S1, SVA was defined as positive (positive sagittal balance). TK was measured from the upper endplate of T5 to the lower endplate of T12 and lumbar lordosis (LL) was measured from the upper endplate of T12 to the upper endplate of S1. Angle of postoperative LIV inclination was measured between the lower endplate of LIV and the horizontal line on the lateral radiographs at first erect after surgery. Positive LIV inclination was defined as having the anterior upper vertebral body of LIV up and the posterior lower vertebral body down. The PJA was defined as the lower endplate of the UIV to the upper endplate of two supra-adjacent vertebrae above the UIV (Fig. 1) [20]. Due to a lack of standardization in the literature, abnormal PJK was not defined. Instead, changes of PJA at first erect after surgery to the final follow-up were calculated.

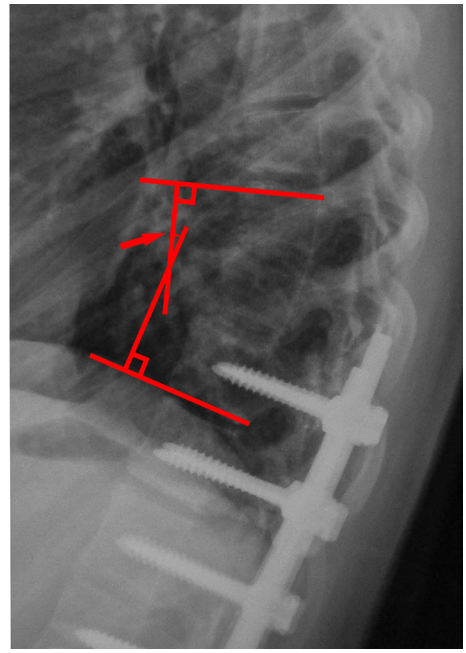

Fig. 1 PJA measurement at lateral radiographs (*red arrow*)

Statistical analyses

Statistical analyses were performed using SAS version 9.2 (SAS Institute, Inc., Cary, NC, USA). All continuous

Table 1 Demographic data of included AIS patients

Characters	Number
Age at operation (year)	14.7 ± 2.1 (range 12–20)
Sex	
Female	37
Male	4
Follow-up period (year)	3.4 ± 1.5 (range 2–8.9)
Riser sign	3.7 ± 0.6 (range 2–5)
PUMC classification	
Ic	3
IId1	38
Lenke classification	
5CN	35
5C–	6
UIV	
Above or equal to T10	18
Below T10	23
LIV	
Above or equal to L3	19
Below L3	22
Length of fusion segments	5.9 ± 1.1 (range 4–8)
Type of pedicle screws alignment	
Discontinuous bilateral	6
Discontinuous unilateral	6
Continuous	29

variables were presented as mean ± standard deviation. Paired t tests were selected to assess the differences of numerical variables. Pearson correlation analysis was performed between LIV inclination and PJA changes. Multiple linear regression analysis was performed to identify risk factors of PJK. Eight potential risk factors were selected for analysis, including locations of UIV (UIV above or equal to T10 and UIV below T10), locations of LIV (LIV above or equal to L3 and LIV below L3), length of fusion segments, types of pedicle screw alignment (discontinuous bilateral, discontinuous unilateral, and continuous), LL at first erect after surgery, LL changes before and after surgery (postoperative LL–preoperative LL), SVA at the first erect after surgery and SVA changes before and after surgery (postoperative SVA–preoperative SVA). The regression formula was conducted and the stepwise regression was used to select independent variables. The inclusion and exclusion criteria were both at 0.15 levels. Statistical significance was assumed at P values of less than 0.05.

Results

A total of 41 patients were included in this study with an average follow-up period of 3.4 years. There were 37 females and 4 male with a mean age of 14.7 years at operation. The PUMC classification was Ic in three patients and IId1 in 38 patients [19]. All patients were categorized as Lenke5C according to the Lenke classification [18]. All patients had undergone posterior selective fusion with pedicle screws with a mean of 5.9 segments being fused. The UIV was above or equal to T10 in 18 patients and below T10 in 23 patients. Meanwhile, the LIV was above or equal to L3 in 19 patients and below L3 in 22 patients. Pedicle screws were implanted continuously at both concave and convex sides in 29 patients, discontinuously at either concave or convex side in six patients and discontinuously at both sides in six patients (Table 1).

Radiographic data were illustrated in Table 2. The average preoperative Cobb angle of the major TL/L curve was 44.1° and was corrected to 9.1° at the last follow-up, showing statistically significant differences ($P < 0.0001$). The average Cobb angles of the minor thoracic curve were 25.2° and 13.4° before surgery and at the last follow-up, respectively, also showing significant differences ($P < 0.0001$). The mean preoperative Cobb angles of major TL/L curve and minor thoracic curve on the reverse bending films were 3.7° and 5.8°, respectively, giving the mean flexibility rate of 89.3 % and 90.3 %, respectively. At the sagittal plane, TK and LL were both increased at first erect after surgery compared with before surgery ($P < 0.0001$). Moreover, TK was continuously increasing during the follow-up period ($P < 0.0001$) whereas LL measurements remained stable overall ($P = 0.128$). No statistical significance of SVA was observed before and immediately after surgery ($P = 0.269$). Nevertheless, it significantly improved during follow-up period ($P = 0.013$). PJA was increased from 2.9° preoperatively to 5.5° immediately after surgery, which showed statistical significance ($P = 0.001$). During follow-up time, it continuously increased to a mean of 10.8° ($P < 0.0001$).

Eight potential risk factors were included for multiple linear regression analysis. Statistical analysis showed that locations of LIV, LL changes before and after surgery and SVA changes before and after surgery were correlated with changes of PJA during follow-up. The formula was as follows:

$$\text{PJA changes }(^\circ) = 12.14 - 5.2 \times \text{locations of LIV} + 0.13 \times \text{LL changes }(^\circ) - 4.3 \times \text{SVA changes (mm)}$$

LIV above or equal to L3 was defined as "1"; LIV below L3 was defined as "2". The adjusted coefficient of determination (R^2) of the formula was 0.23. According to our definitions of these independent variables, we found that that LIV above or equal to L3, higher postoperative LL and a deteriorating negative SVA after surgery were risk

Table 2 Radiographic assessment and comparison of all AIS patients

Measurements	Preoperative	First erect after surgery	Last follow-up	*P* value (preoperative versus first erect)	*P* value (preoperative versus last follow-up)	*P* value (first erect versus last follow-up)
Major TL/L curve (°)	44.1 ± 9.8	6.3 ± 5.1	9.1 ± 6.2	<0.0001	<0.0001	0.001
Minor thoracic curve (°)	25.2 ± 6.8	11.3 ± 7.5	13.4 ± 8.2	<0.0001	<0.0001	0.059
TK (°)	17.6 ± 7.3	24.2 ± 9.5	30 ± 11.8	<0.0001	<0.0001	<0.0001
LL (°)	48.8 ± 13.4	55.9 ± 9.9	58.1 ± 10.2	<0.0001	<0.0001	0.128
SVA (mm)	−34.5 ± 28.5	−42.2 ± 37.8	−13.1 ± 24.5	0.269	0.008	0.013
PKA (°)	2.9 ± 4.6	5.5 ± 4.5	10.8 ± 7.4	0.001	<0.0001	<0.0001

Table 3 Statistical results of multiple linear regression analysis

Variables	Regression coefficients	Standardized regression coefficients	*t* value	*P* value
Constant term	12.14	0	3.79	0.0005
LIV location	−5.2	−0.38	−2.72	0.01
LL changes	0.13	0.22	1.51	0.14
SVA changes	−0.43	−0.22	−1.53	0.13

factors of increased PJA during the follow-up period. The standardized regression coefficients of these three parameters were −0.38, 0.22 and −0.22, respectively, which meant that the location of the LIV played a more important role in PJA changes during follow-up (Table 3).

Pearson correlation test between postoperative LIV inclination and PJA changes was conducted and showed significant differences ($P = 0.022$). Scatter diagram showed a positive linear relationship between PJA changes and postoperative LIV inclination (Fig. 2). If postoperative LIV inclination was >5°, 53.3 % (8/15) of patients had an increase in PJA of more than 5°. However, if postoperative LIV inclination was ≤5°, only 27 % (7/26) of patients had an increase in PJA of more than 5°. Postoperative LIV inclination, therefore, could be an indicator of PJA changes (Figs. 3, 4).

Discussion

PJK is a common complication after spinal deformity surgery. PJK of thoracolumbar region was well evaluated in adult scoliosis, but not in AIS patients [3, 6, 15, 21, 22]. In our study, PJA was significantly increased after selective

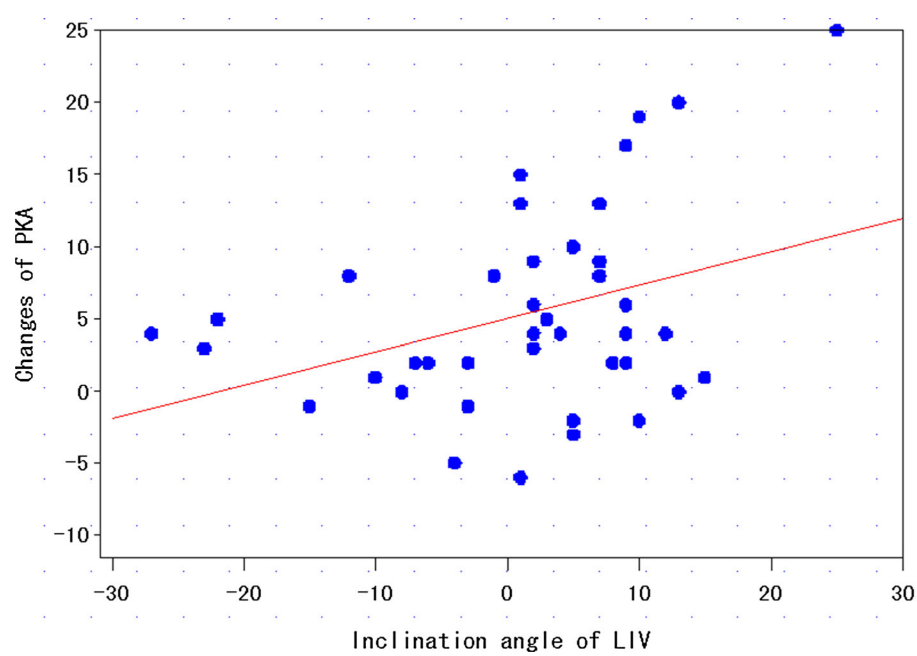

Fig. 2 Relationship between changes of PJA during follow-up and postoperative LIV inclination

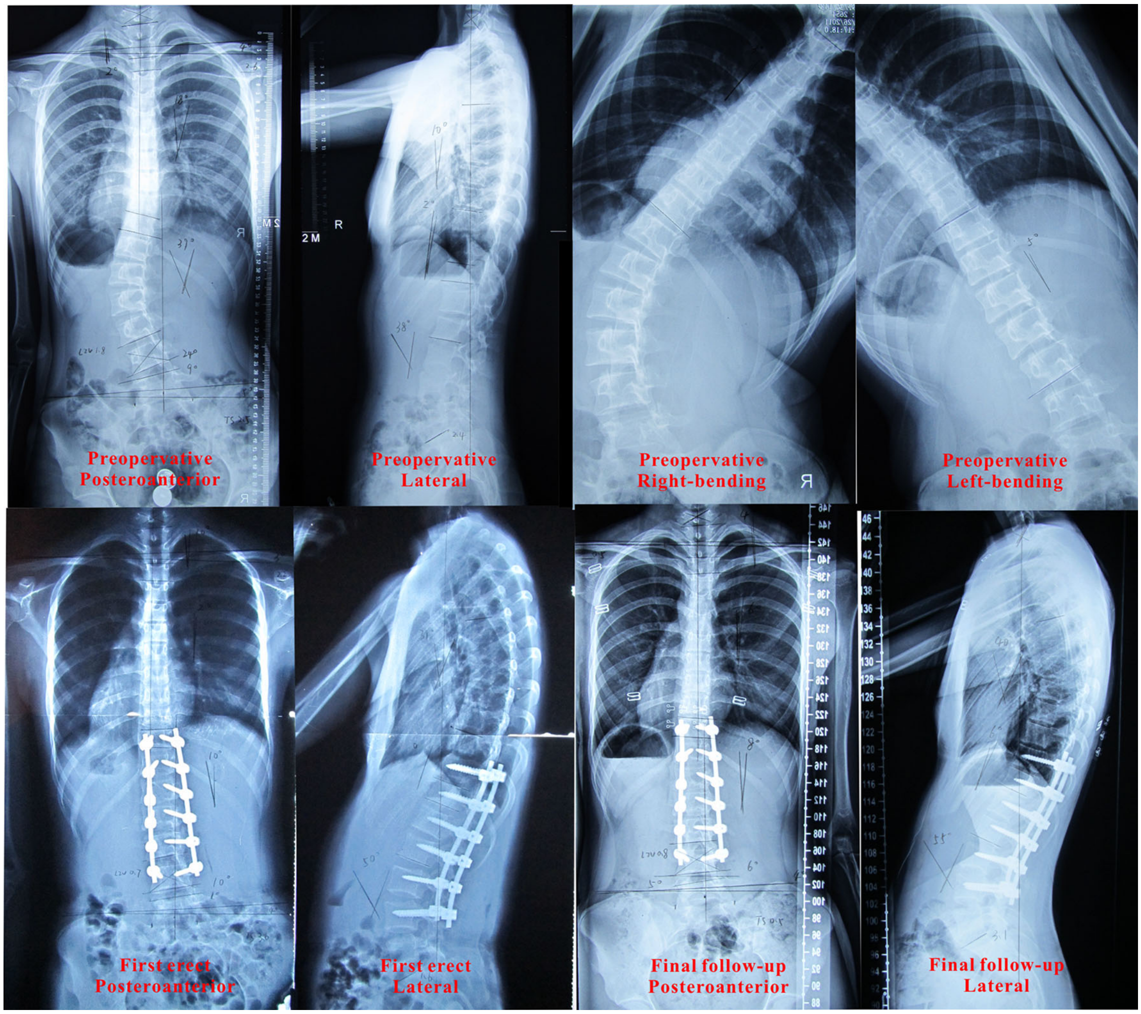

Fig. 3 A 14-year-old female patient with preoperative PJA of zero. Preoperative Cobb angle of the main TL/L curve was 39° and was corrected to 5° on the reverse bending film. Posterior selective fusion from T11 to L4 was performed. Postoperative LIV inclination was 2° and PJA change during 2-year follow-up was 3°

posterior TL/L fusion in AIS patients during the follow-up period. Multiple linear regression analysis identified three risk factors: LIV above or equal to L3, increased LL after operation and worsening negative SVA immediately after surgery. To our knowledge, our study is the first to analyze risk factors of PJK in TL/L idiopathic scoliosis.

It was unexpected to find that LIV above or equal to L3 was a risk factor for increased PJA, because the more distal segments would be left unfused, which might benefit the compensation of sagittal alignment. Wang et al. [12] found that having an LIV below L2 was a risk factor for PJK in AIS patients. They speculated that if more lumbar segments were left unfused, the trunk can adjust to achieve a new overall balance through changes in the lumbar angles and proximal adjustment would be reduced. However, the patients they studied underwent thoracic curve fusion surgery. In our study, most of thoracic segments were left unfused whereas most of lumbar segment were fused. Distal fusion levels were L3 or L4 in most cases. Meanwhile, L3 or L4 was usually the apical vertebra of LL. Thus, we hypothesized that the postoperative inclination of LIV was correlated with PJA changes. Pearson's correlation test further supported our hypothesis revealing statistically significant correlation, and that a postoperative LIV inclination more than 5° increased the risk of development of PJA.

No other study in the current literature has reported that immediate postoperative LL and SVA changes were related to PJK in AIS patients. Yagi et al. [2, 14] used normal global spine alignment as TK + LL + pelvic incidence less than 45° as described by Rose et al. [23] and found inappropriate global spine alignment and greater SVA changes were risk factors of PJK in adult idiopathic scoliosis. Kim et al. [13] reviewed 49 patients with both adolescent and adult idiopathic scoliosis and also found

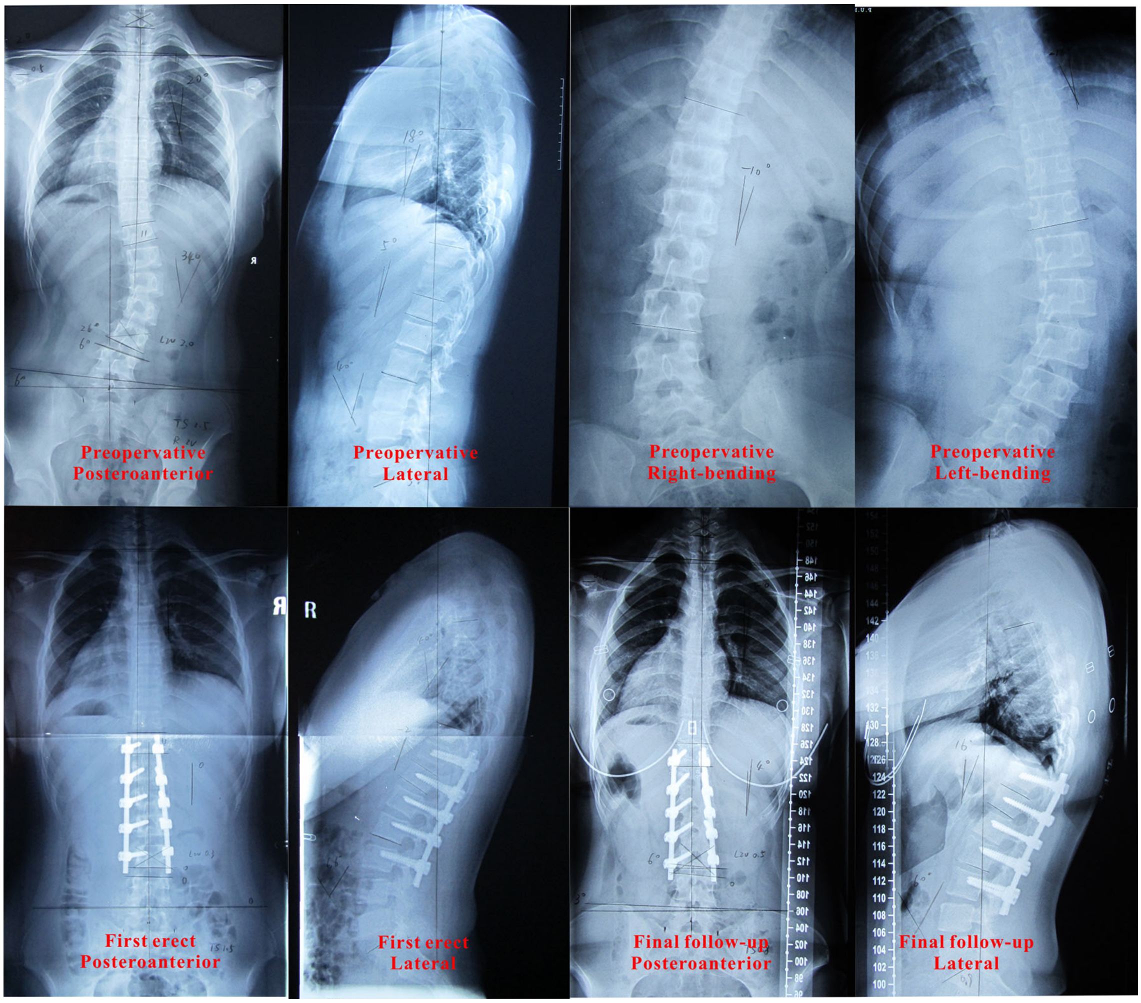

Fig. 4 A 13-year-old female patient with preoperative PJA of 11°. Preoperative Cobb angle of the main TL/L curve was 34° and was corrected to −10° on the reverse bending film. Posterior selective fusion from T11 to L3 was performed. Postoperative LIV inclination was 10° and PJA change during 3.6-years follow-up was 19°

increased SVA changes had a higher likelihood of developing PJK. In another study reported by Kim et al. [16], a higher postoperative LL and larger SVA changes with surgery were observed in patients with PJK requiring revision surgery. Results of these studies were similar with our study with the differences of normally larger LL and negative SVA seen in AIS patients. Whether the definition of normal global spine alignment was suitable for AIS patients could not be concluded since we did not test these mathematical models.

Of the three potential risk factors found in this study, LIV locations played a more important role in PJA changes as the standardized regression coefficient of LIV locations was larger than those of the other two risk factors. LIV selection has always been a source of contention in AIS patients [24]. Our study suggested that LIV locations could also influence postoperative spinal alignments of the sagittal plane, such as PJA.

UIV were located at thoracolumbar region in most cases in this study and regression analysis did not find UIV below T10 or not was correlated with PJA changes. Kim et al. [25] compared 125 adult lumbar deformity patients that underwent T9–T10, T11–T12 and L1–L2 proximal fusion levels and found no significant differences in the prevalence of PJK among three groups. However, in another research of adult degenerative lumbar scoliosis reported by Cho et al. [22], the prevalence of proximal adjacent segment disease (including PJK) was significantly higher in patients of UIV = L1–L2 compared with patients of UIV = T9–T10 and UIV = T11–T12. Taking into consideration of inconsistent results in the literature and the relative small number of patients included in our study, no definite conclusion could be made of the relation of UIV selection and PJA changes.

PJA was increased from 5.5°immediately after surgery to 10.8° at an average follow-up period of 3.4 years in this study. It would probably continue to increase with an extended follow-up period. However, according to the current literature, no study has yet investigated the trend of PJA changes during follow-up. Kim et al. [10] reported a prevalence of 26 % of PJK in AIS patients with a minimum 5-year follow-up (average 7.3 years). Later, they found 27 % of PJK in AIS patients using the same definition at 2-year follow-up [11]. The incidences were comparable at 2-year follow-up and at a minimum 5-year follow-up. Hence this would suggest that PJA after a 2-year follow-up period may be relatively stable, but further studies are still needed in this area.

In terms of limitations in our study, first, a small number of patients were included. This is because only TL/L scoliosis was studied and relative strict inclusion criteria were implemented. Second, instead of defining abnormal PJK, PJA changes during follow-up were used for regression analysis. Bridwell et al. [15] found no difference in clinical outcome scores between patients who developed a PJK of greater or equal to 20° and patients who did not develop PJK following corrective fusion surgery for AIS. Clearly, PJA changes would not correlate with clinical outcomes, either. However, existing definitions of abnormal PJK seldom correlated with clinical outcomes [1–4, 10, 11, 13–18]. In addition, only radiographic data were analyzed. Clinical outcomes, such as Scoliosis Research Society-22 scores and Oswestry Disability Index, and their relationship with PJA changes were not studied. Finally, surgeries were performed by different surgeons, which might have led to inter-surgeon variability in terms of differing surgical techniques and fusion levels selected. Resultantly, this might have had an effect on sagittal alignment at first erect after surgery.

In conclusion, through retrospectively reviewing of 41 TL/L idiopathic scoliosis patients, location of LIV above or equal to L3, higher postoperative LL and deteriorating negative SVA with surgery were found to be risk factors of increased PJA postoperatively. In addition, postoperative LIV inclination of more than 5° might also be an indicator for an increase in PJA.

Conflict of interest No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.

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