Mismatch Between Proximal Rod Contour Angle and Proximal Junctional Angle: A Risk Factor Associated with Proximal Junctional Kyphosis After Growing Rods Treatment for Early-Onset Scoliosis

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Research article

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Abstract

Study Design: A retrospective study

Objectives: To investigate the impact of radiological and surgical factors as well as proximal rod contouring angle (PRCA) on the development of proximal junctional kyphosis (PJK) in early-onset scoliosis(EOS) patients after growing rod (GR) treatment.

Methods: We reviewed a consecutive series of EOS patients who had undergone growing rod (GR) treatment between 2009 and 2018 (minimum follow-up of 2 years) at a single institution. Patients were divided into PJK and non-PJK groups according to the occurrence of PJK or not during the follow-up periods. The demographic data, surgical strategies, and radiographic parameters were recorded and compared between the PJK and non-PJK groups. PJK was defined as a PJA $\geq$ 10° at the last follow-up. PRCA was defined as the angle between the cephalad endplate of the UIV and the lower endplate of the second vertebra caudal to UIV and the PJA-PRCA was defined as the difference between the values of PJA and PRCA. Logistic regression was also performed to identify the risk factors for the occurrence of PJK.

Results: This study finally included 95 patients. The mean age at the index surgery was 6.5 $\pm$ 2.2 years. Mean follow-up lasted 4.4 $\pm$ 1.9 years. Lengthening procedures averaged 4.0 $\pm$ 1.8 times. There were 20 patients who were observed with PJK (the incidence, 21.1%). In comparison with the non-PJK group, the PJK group showed a larger preoperative coronal cobb angle (81.8 $\pm$ 20.6° vs 70.4 $\pm$ 12.4°, P=0.041) and global kyphosis (GK) (56.0 $\pm$ 15.3° vs. 45.9 $\pm$ 12.9°, P=0.044), as well as a larger GK correction (40.4% $\pm$ 10.0% vs. 30.0% $\pm$ 14.2%, P=0.035). In addition, the PJK group had significantly larger postoperative PJA (10.8 $\pm$ 3.1 vs. 5.3 $\pm$ 3.1, P $\leq$ 0.001) and greater postoperative PJA-PRCA (5.3 $\pm$ 3.0 vs. 3.66 $\pm$ 2.9, P=0.031). The proportion of patients with a value of PJA-PRCA greater than 5° in PJK group was significantly higher than that in the non-PJK group. Multiple logistic regression showed that preoperative GK $\geq$ 50°, postoperative PJA $\geq$ 10 and postoperative PJA-PRCA $\geq$ 5° were the risk factors in predicting PJK after GR treatment.

Conclusions: More than one-fifth EOS patients experienced PJK after GR treatment. Besides greater preoperative GK and larger postoperative PJA, PJA-PRCA mismatch may be an independent risk factor of PJK occurrence.

Introduction

Early-onset scoliosis (EOS) refers to a deformity that presents before 10 years old and progressed rapidly at early stage[1]. Definitive spinal fusion performed at young age may result in a short trunk, pulmonary dysfunction, and even iatrogenic thoracic insufficiency syndrome[2]. In past decades, growth friendly technique has become a mainstay of treatment for EOS patients due to its effectiveness in controlling spinal deformity while permitting spinal column growth and pulmonary system development[3]. However, it can't be ignored that this technique has a high incidence of complications, such as surgical site infection, implant-related and alignment-related complications[4–6].

Proximal junctional kyphosis (PJK) is a common alignment-related complications observed in adults and adolescents after surgery for scoliosis or kyphosis[7, 8]. Also, a significant proportion of children under the age of 10 developed PJK. Chen[9] reported occurrence of PJK in 21 of 113 congenital scoliosis (CS) children who underwent posterior instrumented fusion. At the same time, PJK was reported in EOS patients who accepted growth-friendly treatment, such as vertical expandable prosthetic titanium rib technique(VEPTR)[10] and growing rods treatment(GR)[11], with a rate ranging from 12–56%[10–12]. Several risk factors, radiological or surgical, associated with PJK had been reported, including preoperative hyperkyphosis[13], pelvic incidence[14, 15], locations of upper instrumented vertebra (UIV) [16] and lower instrumented vertebra (LIV)[11]. In addition, some studies have turned their attention to the proximal junctional area and found that the mismatch between proximal rod contour angle (PRCA) and proximal junctional angle (PJA) may be a possible risk factor of PJK in degenerative scoliosis[11].

To the best of our knowledge, the impact of the mismatch between PJA and PRCA on the occurrence of PJK in EOS has not been investigated. Thus, the current study aimed to investigate the incidence and risk factors of PJK and further to clarify the association between PRCA and PJK in EOS patients receiving GR treatment.

Material And Methods

Study sample

A series of consecutive patients with EOS who had undergone GR treatment between January 2009 and May 2018 were identified from our spinal deformity database. Inclusion criteria to this study were as follows: (1) patients aged before 10 years old at index surgery; (2) had at least 2 lengthening procedures; and (3) a minimum follow-up of 2 years with complete radiographs. Exclusion criteria were as follows: (1) previous history of spinal surgery; (2) a distal anchor at the sacrum or pelvis; (3) VEPTR. Clinical demographic data including age at the index surgery, gender and etiology were recorded. Surgical data including type of GR (single or dual rods), location of UIV and LIV, anchor type (pedicle screw or hook or hybrid), and the times and intervals of lengthening procedures were also collected. This study was approved by the Institutional Review Board of Affiliated Drum Tower Hospital of Nanjing University Medical School, and informed consent have been exempt from requirement in the study.

Surgical strategy

All surgeries were performed by a single surgical team who were well experienced with the GR treatment. The surgical strategy consisted of the index surgery and the following periodical lengthening procedures. In the index surgery, UIV and LIV for each patient were determined based on evaluations of age, scoliotic deformity and sagittal plane of the spine. Basically, the UIV and LIV were chosen in the stable zone from T1 to T5 and L1 to L5, respectively. During the index surgery, only upper and lower ends of the instrumentation area require subperiosteally exposure. Generally, polyaxial pedicle screws were used as anchors at the proximal and distal sites. If the pedicle was too small, a laminar hook was placed instead. Then, single/dual rods were contoured to normal sagittal alignments, placed with a tandem in a

submuscular manner and attached to the screws at either end. Correction of the main curve was achieved once all set screws were tightened under traction. Lengthening procedure was scheduled every 8–12 months and was performed through a small midline incision with 1-2cm distraction. Somatosensory evoked potential and motor evoked potentials were applied in all surgical procedures.

Radiographic evaluation

All the radiographic measurements were performed on the Picture Archiving and Communications Systems (PACS) workstation. Radiographs were taken before and after the index surgery, as well as during each lengthening procedure. Standing postero-anterior radiographs were used for the measurements of the following parameters: coronal Cobb angle, thoracic kyphosis (TK), global kyphosis (GK), lumbar lordosis (LL), sacral slope (SS), pelvic tilt (PT), pelvic incidence (PI), sagittal vertical axis (SVA), PRCA and PJA. PJA was defined as the angle between the caudal endplate of the UIV and the cephalad endplate of the second supradjacent vertebra above the UIV; PRCA was defined as the angle between the cephalad endplate of the UIV and the caudal endplate of the second vertebra caudal to the UIV (Fig. 1.). The PJA-PRCA was defined as the difference between the values of PJA and PRCA.

PJK was diagnosed when the PJA met the following two criteria: (1) PJA no less than 10°; (2) at least 10° greater than preoperative measurement[17]. According to Yagi's study[18], PJK was divided into three types: (1) Type 1, ligamentous failure; (2) Type 2, bone failure, such as fracture at or above the UIV; and (3) Type 3, implant/bone interface failure.

Statistical Analyses

Analyses were performed by SPSS version 22.0 software (SPSS Inc., Chicago, IL). Patients were divided into PJK and non-PJK group based on whether PJK developed during the follow up or not. All data were reported as mean $\pm$ standard deviation. The significance of differences between the two groups was determined by independent-sample t test. The univariate analysis by Chi-square test was used to compare the differences of categorical variables between the PJK group and non-PJK group, and further served as a screening tool to select the possible candidates for the logistic regression analysis. Subsequently, logistic regression analysis was performed on predictors with a univariate P value of less than 0.10 to analyze the covariate effects of the possible indicators for the development of PJK. A P value of less than 0.05 was considered statistically significant.

Results

Baseline Data

A total of 95 consecutive patients (45 boys and 50 girls) who accepted GR treatment were ultimately included in this study. The baseline patient characteristics are shown in Table 1. The mean age at the index surgery was 6.5 ± 2.2 years. Among them, the etiologies were classified as: congenital in 61 patients, neuromuscular in 16, idiopathic in 11, and syndromic in 7, respectively. There were 73 patients treated

with dual GR and 22 with single GR. Pedicle screws were placed as anchors proximally in 78 patients, while hooks in 9 and hybrid (screws in combination with hooks) in 8 respectively.

General Results After GR Treatment

A total of 383 lengthening procedures were performed, with an average of 4.0 ± 1.8 procedures per patient. The mean lengthening interval and follow-up duration were 11.0 ± 1.1 months and 52.4 ± 23.0 months, respectively. Fourteen patients who reached skeletal maturity underwent removal of the GR implants and definitive fusion while one patient keep close follow-up without subsequent surgery after 5 times lengthening procedures.

As shown in Table 2, the major curve experienced satisfactory correction after the index surgery ($73.0 \pm 18.8^\circ$ VS. $36.8 \pm 11.4^\circ$, $P < 0.001$) and increased slightly during subsequent lengthening surgery. The preoperative T1-S1 height increased from 24.7 ± 3.3 cm to 27.8 ± 4.1 cm after the index surgery ($P < 0.001$), and increased to 32.9 ± 4.3 cm at final follow up. On the sagittal plane, GK decreased significantly after the index surgery and increased slightly during the whole follow-up period.

Till the latest follow-up, PJK was identified in 20 patients. In addition, 13 patients developed rod fracture, 3 experienced screw loosening and 1 developed distal junctional kyphosis, which were treated in the next lengthening procedures. There were 3 patients with wound superficial infections who were treated successfully by dressing changes daily and antibiotic treatment. No neurological deficit occurred in this cohort either in the index surgery or in the subsequent lengthening procedures.

Incidence, classification and progression of PJK

The overall incidence of PJK in our cohort was 21.1%. There were 17 patients with type 1 PJK and 3 with type 3 PJK, respectively. None of our cohort had a type 2 PJK. Among the patients with PJK, 5 patients developed PJK within 6 months after the index surgery, 8 after the first lengthening procedures, 5 after the second lengthening procedures, 1 after the third lengthening procedure and 1 after the forth lengthening procedure. In the PJK group, the average PJA increased from $5.9 \pm 4.1^\circ$ to $10.8 \pm 3.1^\circ$ after the index surgery, and continuously increased to $17.3 \pm 7.2^\circ$ at final follow-up. Six cases of PJK continued to progress while the other 14 cases were relatively stable. For these progressive PJK patients, brace treatment was prescribed. At the latest follow-up visit, only one patient received a revision surgery due to pulling out of the proximal hooks.

Comparisons between PJK and non-PJK groups

Comparisons between PJK and non-PJK groups revealed that younger age at the index surgery was associated with the occurrence of PJK. However, no significant difference was observed in terms of gender, type of GR and number of lengthening procedures or intervals between the two groups. (Table 3)

The radiographic characteristics of both groups are listed in Table 4. Compared with the non PJK group, the PJK group had a larger preoperative Cobb angle ($81.8 \pm 20.6^\circ$ VS. $70.4 \pm 12.4^\circ$, $P = 0.041$), larger

preoperative GK ($56.0 \pm 15.3^\circ$ VS. $45.9 \pm 12.9^\circ$, $P=0.044$) and greater GK correction ($40.4 \pm 10.0\%$ vs. $30.0 \pm 14.2\%$, $P=0.035$).

The change in PJA, PRCA and PJA-PRCA were also compared between the two groups. Patients in the PJK group had significantly larger PJA postoperatively ($10.8 \pm 3.1^\circ$ VS. $5.3 \pm 3.1^\circ$, $P=0.001$) and at final follow up ($17.3 \pm 7.2^\circ$ VS. $6.4 \pm 4.5^\circ$, $P=0.001$), whereas there was no difference in preoperative PJA ($5.9 \pm 4.1^\circ$ VS. $5.7 \pm 3.1^\circ$, $P=0.835$). In addition, the postoperative PRCA was not significantly different between these two groups ($8.8 \pm 2.6^\circ$ VS. $9.2 \pm 4.2^\circ$, $P=0.781$). With regards to the relationship between PJA and PRCA, the preoperative PJA-PRCA ($3.6 \pm 2.2^\circ$ VS. $3.4 \pm 2.1^\circ$, $P=0.801$) showed no difference while the postoperative PJA-PRCA ($5.3 \pm 3.0^\circ$ VS. $3.7 \pm 2.9^\circ$, $P=0.031$) were significantly higher in PJK group than in non-PJK group. Also, the preoperative and postoperative values in PT, PI, LL and SS did not differ significantly between the two groups.

Risk factors for PJK

As shown in Table 5, the possible candidates from the univariate analysis which were associated with PJK included age at index surgery ≤ 6 yr, preoperative GK $\geq 50^\circ$, postoperative PJA $\geq 10^\circ$, postoperative PJA $\leq 10^\circ$ and postoperative PJA-PRCA $\geq 5^\circ$. The logistic regression analysis revealed that preoperative GK $\geq 50^\circ$, postoperative PJA $\geq 10^\circ$ and postoperative PJA-PRCA $\geq 5^\circ$ were independent risk factors of the occurrence of PJK.

Discussion

Incidence and mechanism of PJK after GR treatment

According to previous studies, the incidence of PJK in EOS patients after GR treatment varied from 12% to 56%, which was mainly due to different inclusion criteria and surgical strategies[10-12]. The incidence of PJK in our study cohort was 21.1% over an average 52.8 ± 22.2 months of follow-up. It's remarkable that PJK in this study mainly occurs after the first distraction surgery. Li[19] revealed that all patients developed PJK within the first year after VEPTR treatment. On the other hand, Wijdicks et al.[20] reported that the occurrence of PJK in patients treated with [magnetically controlled growing rod](#) increased as time progresses but had no correlation to the number of distractions.

Several studies tried to explain the patho-mechanism of PJK. A biomechanical study on adult scoliosis suggested that the dissection of posterior intervertebral elements might lead to the increase of the mechanical stresses within the junctional area. Also, the injury of the paraspinal musculature and the extensive dissected facet joints during the surgery may destroy the integrity and stability of the posterior structures of the spine[21]. According to our experience, the lengthening procedure itself is a local distraction surgery, which has a tendency to increase the kyphosis of the implant area or junctional area, eventually leading to the occurrence of PJK. In our study, the most common type of PJK was ligamentous failure which developed in 85% (17/20) patients. Our finding is in line with the study by Chen[9], but

inconsistent with the study by Wang[22] who reported that implant/bone interface failure was the major type of PJK in congenital scoliosis patients receiving posterior short fusion.

Association of PJA-PRCA mismatch with PJK

Currently, there are still no studies reporting the mismatch between PJA and PRCA as a risk factor for PJK in EOS patients receiving GR treatment. As a parameter to represent the proximal rod bending, the PRCA stays unchanged because the position of the screw and the rod is relatively fixed after the index surgery and allows us to indirectly measure the contouring of the proximal part of the rod. Thus the PJA-PRCA was proposed to reflect the matching between the proximal rod contouring and supradjacent regional spinal alignment. In our study, there was no significant difference in PRCA and preoperative PJA-PRCA between the two groups. However, the PJK group has a significantly higher proportion of patients with a value of PJA-PRCA greater than 5° than that in the non-PJK group. We believe that PJK might be avoided if the postoperative PJA-PRCA matches well. But when the proximal area of the instrumentation is excessively corrected, resulting in mismatched postoperative PJA-PRCA, the risk of PJK will be greatly increased. Of note, similar findings have been observed in previous studies. Yagi et al.[18] reported that the inadequate restoration of global sagittal alignment was a significant risk factor for PJK in adult scoliosis patients undergoing long instrumented spinal fusion. Yan[23] demonstrated that mismatch between postoperative PJA and PRCA led to a proximal compensation, namely PJK in degenerative scoliosis. After reviewing 84 adolescent idiopathic scoliosis patients, Wang et al.[24] found that larger postoperative PJA-PRCA, especially those with PJA-PRCA greater than 5° were risk factors for PJK.

In the previous literature, two methods of contouring angle measurements of the proximal part of the rod were reported. In Yan's[23] study, PRCA was defined as the angle between the first two proximal screws in sagittal plane after surgery in DS. The second method is that of Lonner used in AIS patients and the PRCA was defined as the Cobb angle between the UIV and once vertebra caudal to the UIV. These two methods have one thing in common, that is, they both use a contouring angle between 2 vertebra (UIV and UIV-1). In our study, we proposed a new measurement method to reflect the proximal rod contouring (PRCA was defined as the angle between the cephalad endplate of the UIV and the lower endplate of UIV-2).

Consequently, we propose some possible mechanisms. A large PJA-PRCA means the proximal rod is contoured insufficiently, resulting a greater biomechanical stress concentrated in the junctional area and leading to the occurrence of PJK subsequently. Moreover, to get satisfactory correction results, the proximal region may sustain excessive forces during the surgery. According to the Hueter-Volkman principle that compression forces inhibit growth and tensile forces stimulate growth, the posterior column of spine grows faster than the anterior column after the index surgery, further aggravating the kyphosis of the proximal junctional area. Therefore, even if the PJA is less than 10° before the lengthening procedures, it may progress to more than 10° after the subsequent distraction. Another cause of PJK is related to the particularity of GR treatment itself. GR treatment is different from other operations in that besides the index surgery, subsequent lengthening procedures are also needed. The stress generated

during the lengthening procedures will be transferred to the junctional area, making the stress concentration, and finally lead to the occurrence of PJK. This is consistent with Bess et al.¹² findings on the complications of GR treatment.

General risk factors of PJK

In this study, preoperative hyperkyphosis was also identified as an independent risk factor associated with PJK. This is also consistent with previous research. Chen et al.[10] reported that hyperkyphotic EOS ($TK \geq 50^\circ$) tended to experience increased complications, such as rod fracture and PJK. Lee et al.[25] pointed out that correction surgery would impact the overall sagittal balance of the spine and PJK might be an early-stage adjustment of the overall balance compensation by the trunk. In severe kyphotic deformity, surgeons pay more attention to achieving satisfactory correction. Excessive forces were applied to the kyphosis area to reconstruct the sagittal plane, leading to the stress concentration and eventually resulting in the occurrence of PJK.

We also found postoperative PJA $\geq 10^\circ$ was a significant independent risk factor for PJK. Previously, several studies also detected larger postoperative PJA in the PJK group than the non-PJK group[11, 16]. Patients with postoperative PJA greater than 10° are more likely to develop PJK, which is helpful for early prediction and intervention. We inferred that this might be related to the improper selection of UIV or the insufficient contouring rod during the index surgery.

Although we find no significant differences between the location of UIV and LIV in PJK group and non-PJK group, some previous studies reported different opinions. Pan[16] reported UIV distal to T2 leads to an increasing stress concentration in the junctional area, which may accelerate the occurrence of PJK. Similarly, Watanabe[11] demonstrated that an LIV at or cranial to L3 may change the stress on the spine and then increase the risk of PJK.

Clinical relevance and limitations

The clinical relevance of our study lies in emphasizing the importance of appropriate rod contouring at the proximal junctional area in preventing the occurrence of PJK. During the index surgery, the curvature of the rods should be shaped into a slightly kyphotic profile harmoniously matching the proximal spinal curve when contouring the rods. For patients with hyperkyphosis, the operation of excessive correction of kyphosis leading to the stress concentration on proximal junctional area should be avoided as much as possible. Additionally, for patients with postoperative PJA $\geq 10^\circ$, brace treatment will be prescribed.

Our study has several limitations. First, it was a retrospective study with a relatively short follow-up. Second, we were unable to evaluate the impact of PJK on clinical outcomes because patients are too young to fill out questionnaire by themselves. Despite these limitations, all patients were treated by the same surgical strategy and protocol which reduced the impact of the variety of surgical procedures and ensured the homogeneity of surgical results.

Conclusion

In conclusion, the prevalence of PJK in patients with EOS undergoing growing rod treatment was 21.1%. PJK mainly occurred after the first lengthening procedures. Preoperative $GK\geq 50^\circ$, postoperative $PJA\geq 10^\circ$ and postoperative $PJA-PRCA\geq 5^\circ$ were the risk factors of occurrence of PJK.

Abbreviations

EOS

Early onset scoliosis; GR:Growing rod; PJK:Proximal junctional kyphosis; VEPTR:Vertical expandable prosthetic titanium rib technique; UIV:Upper instrumented vertebra; LIV:Lower instrumented vertebra; CS:Congenital scoliosis; DS:Degenerative scoliosis; PRCA:Proximal rod contour angle; PJA:Proximal junctional angle; TK:Thoracic kyphosis; GK:Global kyphosis; LL:Lumbar lordosis; SS:sacral slope; PT:Pelvic tilt; PI:Pelvic incidence; SVA:sagittal vertical axis

Declarations

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Authors' contributions

Xu Sun, Bin Wang and Zezhang Zhu planned the study; Bo Yang, Liang Xu, Changzhi Du and Muyi Wang collected the data; Bo Yang did the statistics and wrote the manuscript; Xu Sun and Yong Qiu did the quality control of data and proofreading of the manuscript. The authors read and approved the final manuscript.

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Availability of data and materials

A limited data set with fields reported in this paper is available upon request via email to the corresponding author, with no limitations on the reuse of the data.

Ethics approval and consent to participate

This study was approved by the Institutional Review Board of Affiliated Drum Tower Hospital of Nanjing University Medical School.

Consent for publication

All authors have read the manuscript and give consent for publication.

Competing interests

The authors declare no competing interests. The manuscript submitted does not contain information about medical device(s)/drug(s). No relevant financial activities outside the submitted work.

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Tables

Table1 Basic information

Sample size	95
Sex(M/F)	45/50
Age at index surgery (y)	6.5±2.2(2.0-10.0)
Follow up (y)	4.4±1.9
Lengthening procedures	4.0±1.8
Diagnosis	
Congenital	61
Neuromuscular	16
Idiopathic	11
Syndromic	7
Single/Dual rod(s)	22/73
Proximal anchors (screws/hooks/hybrid)	78/9/8

Table2 Comparison of radiographic parameters between preoperative, postoperative and final follow-up

	Preoperative	Postoperative	Follow up	P
Major coronal Cobb (deg.)	73.0±18.8	36.8±11.4	44.6±15.5	0.000
Proximal junctional angle (deg.)	6.7±3.3	7.8±3.9	9.0±6.0	0.146
T1-S1 spinal height (cm)	24.7±3.3	27.8±4.1	32.9±4.3	0.000
T2-12 thoracic kyphosis (deg.)	40.2±12.5	29.8±10.2	34.7±10.7	0.000
Global kyphosis (deg.)	49.8±17.4	34.8±9.7	40.2±10.3	0.000
Lumbar lordosis (deg.)	50.4±12.2	45.9±11.7	46.9±8.3	0.136

Table3 Comparison in Demographic and Surgical Data			
	PJK Group	Non-PJK Group	P
Sex(male/female)	7/13	38/37	0.212
Age at index surgery(y)	5.5±1.9	6.7±2.2	0.028
Follow up (y)	5.1±2.3	4.6±1.6	0.271
Diagnosis			
Congenital	10	51	0.514
Neuromuscular	5	11	
Idiopathic	3	8	
Syndromic	2	5	
Single/Dual rod(s)	6/14	16/59	0.414
Proximal anchors (hooks/screws/hybrid)	1/16/3	8/62/5	0.113
Location of UIV			
T1	1	10	
T2	2	24	
T3	5	23	
T4	6	14	
T5	6	2	
T6	0	1	
T7	0	1	
Location of LIV			
L1	1	6	
L2	1	12	
L3	5	30	
L4	13	23	
L5	0	4	
Distraction times	4.8±2.0	4.1±1.6	0.121
Distraction intervals(m)	10.8±2.7	11.2±2.0	0.435

Table4 Comparison in Radiographic Measurements			
	PJK Group	Non-PJK group	P
PJA			
Preoperative	5.9±4.1	5.7±3.1	0.835
Postoperative	10.8±3.1	5.3±3.1	0.001
Latest follow-up	17.3±7.2	6.4±4.5	0.001
PRCA			
Pre-op PJA-PRCA	3.6±2.2	3.4±2.1	0.801
Post-op PJA-PRCA	5.3±3.0	3.7±2.9	0.031
Coronal Cobb			
Preoperative	81.8±20.6	70.4±12.4	0.041
Postoperative	40.0±13.7	39.4±9.8	0.860
Latest follow-up	45.4±14.7	42.2±13.8	0.609
TK			
Preoperative	43.9±3.3	38.2±16.4	0.481
Postoperative	31.9±7.8	31.8±13.0	0.624
Latest follow-up	35.2±11.5	34.6±28.6	0.677
GK			
Preoperative	56.0±15.3	45.9±12.9	0.044
Postoperative	32.5±7.4	30.8±8.8	0.373
Latest follow-up	42.1±9.2	36.8±8.2	0.339
Correction rate(%)	40.4±10.0	30.0±14.2	0.035
LL			
Preoperative	44.7±16.3	47.4±12.6	0.311
Postoperative	42.3±15.8	48.8±11.1	0.369
Latest follow-up	51.3±8.8	52.3 ±12.5	0.144
PT			
Preoperative	37.7±8.6	39.7±11.1	0.589
Postoperative	38.3±6.3	39.5±8.9	0.675

Latest follow-up	40.6±8.9	39.8±8.5	0.821
SS			
Preoperative	30.3±9.8	34.9±10.6	0.224
Postoperative	35.7±8.5	34.3±11.2	0.709
Latest follow-up	34.9±8.0	35.6±9.7	0.845

Table5 Comparison of the Risk Indicators Between PJK Group and Non-PJK Group			
	PJK Group	Non-PJK Group	P
Age at index surgery			
≤6yr	13	22	0.003
>6yr	7	53	
Postoperative PJA			
≤10	10	57	0.023
>10	10	18	
Preoperative Cobb			
≤80	9	48	0.123
>80	11	27	
Preoperative GK			
≤50	8	53	0.011
>50	12	22	
Postoperative PRCA			
≤10	10	21	0.096
>10	8	41	
Postoperative PJA-PRCA			
≤5	8	58	0.001
>5	12	17	

Table 6 Multivariate Analysis of PJK Risk Factors						
Parameters	B	SE	Wald	df	P	Exp(B)
Age at index surgery ≤ 6 yr	0.761	0.771	0.976	1	0.323	2.141
Postoperative PJA ≥ 10	0.165	0.530	3.417	1	0.045	3.207
Postoperative PRCA ≤ 10	0.021	0.013	2.660	1	0.103	1.021
Postoperative PJA-PRCA ≥ 5	1.529	0.570	10.439	1	0.037	4.615
Preoperative GK ≥ 50	1.317	0.632	6.797	1	0.041	3.732

Figures

Figure 1

This 5-year-old boy was diagnosed with idiopathic scoliosis, showing a 60° Cobb angle and 4° PJA before surgery (A). After the index surgery, the radiographs showed a 12° PJA and a 7° PRCA (B). At 6-month

follow-up, the PJA increased to 23°(C). After the first lengthening surgery, the PJA was 19° (D). After completion of 7 years of follow-up (7 lengthening), the PJA increased to 31° (E). This patient underwent definitive fusion at the age of 13 years old and the PJK was corrected (F).

Figure 1

The measurement of proximal rod contouring angle (PRCA) and proximal junctional angle (PJA). PRCA: the angle between the UIV and UIV-2. PJA: the angle between the UIV and UIV+2.