

# Large Difference between Proximal Junctional Angle and Rod Contouring Angle is a Risk Factor for Proximal Junctional Kyphosis

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## Research article

**Keywords:** adolescent idiopathic scoliosis, proximal junctional kyphosis, proximal junctional angle, rod contouring angle

**Posted Date:** October 2nd, 2019

**DOI:** <https://doi.org/10.21203/rs.2.15564/v1>

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**Version of Record:** A version of this preprint was published at World Neurosurgery on April 1st, 2020. See the published version at <https://doi.org/10.1016/j.wneu.2020.01.136>.

# Abstract

**Background:** There are several risk factors for proximal junctional kyphosis (PJK) in adolescent idiopathic scoliosis (AIS) surgery. Decreased rod contouring angle (RCA) has been proposed as a risk factor for PJK, but the role of difference between proximal junctional angle (PJA) and RCA (PJA-RCA) has not been fully investigated. The aim of this study was to assess the role of PJA-RCA for the development of postoperative PJK in AIS.

**Methods:** We performed a retrospective analysis of 96 AIS patients who underwent posterior segmental spinal instrumentation and fusion between the years 2012 and 2018 (minimum 1.5-year and average 2-year follow-up) at a single institution. Each patient was measured on preoperative, postoperative and final follow-up long-cassette standing radiographs. The PJA-RCA was regarded as a new definition that reflects the match degree between proximal rod contouring and vertebra curvature, and radiographic parameters were compared between PJK and non-PJK group.

**Results :** Among the 96 patients with a mean age of 14.00 years ( $\pm 0.82$ ), the overall incidence of PJK was 22%. PJK group showed a significantly greater preoperative SVA ( $P = 0.032$ ) and larger correction of SVA ( $P = 0.007$ ) than non-PJK group. At the last follow-up, PJK patients had significantly greater LL ( $P = 0.046$ ). Patients in the PJK group had significantly greater preoperative PJA-RCA than the non-PJK group ( $4.07 \pm 3.30$  vs.  $1.42 \pm 4.28$ ,  $P = 0.024$ ). However, RCA was not significantly different between two groups ( $3.88 \pm 4.34$  vs.  $2.86 \pm 3.36$ ,  $P = 0.405$ ). In addition, Pearson correlation coefficient showed a significant correlation between the change of SVA and the last follow-up PJA ( $r = -0.208$ ,  $P = 0.042$ ). Preoperative PJA-RCA and postoperative PJA-RCA demonstrated similar results which showed a strong correlation with the last follow-up PJA ( $r = 0.528$  and  $r = 0.532$  respectively,  $P < 0.000$ ).

**Conclusions:** As a new reflex of improper rod contouring, large PJA-RCA is a risk factor for PJK in AIS, and PJK might be a compensation mechanism rather than complication when spine is shifted and overcorrected.

**Keywords:** adolescent idiopathic scoliosis, proximal junctional kyphosis, proximal junctional angle, rod contouring angle.

## Background

Patients with all-pedicle screw instrumentation had the greatest curve correction percentage, maintenance of this correction in the coronal and sagittal planes, less blood loss, shorter operation time, higher patient satisfaction and better self-assessment of appearance in operative treatment of adolescent idiopathic scoliosis (AIS).[1–3] Based on these advantages, all-pedicle screw construct has been gradually adopted as the current trend of adolescent idiopathic scoliosis surgeon. However, Kim et al[4] reported that all-pedicle screw construct demonstrated a significantly higher two-year postoperative prevalence of proximal junctional kyphosis (PJK) (35%) compared with the hook-only (22%) and hybrid (29%) groups. Helgeson et al[5] had similar conclusion and found adjacent level proximal kyphosis was

significantly increased with pedicle screws. As one of the most common adjacent pathology, PJK is typically defined as the angle between the inferior endplate of the upper instrumented vertebra (UIV) and the superior endplate of the UIV+2 is 10° or greater, and at least 10° greater than the preoperative value.[6] The incidence of PJK in AIS patients following posterior instrumented arthrodesis ranges from 14% to 35%.[4, 7–9]

While patients with PJK may be initially asymptomatic with worsening degrees of PJK, they can develop the structural failures that characterize proximal junctional failure (PJF), which may be accompanied by subsequent pain, neurologic deficit, gait difficulties, sagittal imbalance, social isolation and higher need for revision surgery.[10] Based on previous studies, multiple risk factors which correlate significantly with PJK have been extensively evaluated and reported. These include a larger preoperative thoracic kyphosis angle, greater immediate postoperative thoracic kyphosis angle decrease, thoracoplasty, the use of a pedicle screw at the top vertebra, autogenous bone graft, distal fusion below L2, and male sex.[4, 7] Ferrero et al[8] found that patients with high pelvic incidence and consequently large lumbar lordosis (LL) and thoracic kyphosis (TK) were more at risk of PJK. Furthermore, optimal rod contouring has also been proposed as a means to prevent PJK. Lonner et al[11] reported that decreased rod contour angle (RCA: the Cobb angle between the UIV and one vertebra caudal to the UIV) were one of the major risk factors for PJK in AIS. (Fig. 1)

However, as a new definition that reflects the relative match degree between proximal rod contouring and vertebra curvature, the impact of PJA-RCA has not been fully investigated and warrants further study in AIS patients with posterior spinal fusion.

## Materials And Methods

### Subjects

We performed a retrospective analysis of 96 AIS patients who underwent posterior segmental spinal instrumentation and fusion between the years 2012 and 2018 at a single institution. Minimum 1.5-year and average 2-year follow-up was required.

Inclusion criteria of this study were as follows: (1) diagnosis of AIS; (2) single-stage posterior spinal fusion with an all-pedicle screw construct; (3) instrumented levels more than 5; (4) complete radiographic follow-up with distinct radio graphic landmarks.

Exclusion criteria included the following: (1) patients diagnosed with early onset scoliosis and neuromuscular scoliosis; (2) hybrid instrumentation constituted of hooks and wires; (3) history of Smith-Petersen osteotomy, pedicle subtraction osteotomy, vertebral column resection, and (5) reoperations related to the pedicle screw system.

### Data Collection and Radiographic Parameters

Each patient was measured on preoperative and postoperative long-cassette standing radiographs. Basic demographic and surgical data collected included age at surgery, gender, Risser, and levels instrumented. The radiological parameters were as follows: (1) Pelvic parameters: pelvic incidence (PI) and pelvic tilt (PT). (2) Spinal parameters: T5-T12 thoracic kyphosis (TK), lumbar lordosis (LL), sagittal vertical axis (SVA). (Fig. 2) (2) Other parameters: preoperative and postoperative PJA, RCA (Figure 1), and Cobb angle of the main curve.

Based on the criteria that PJK is defined as a PJA more than 10°, and at least 10° greater than the preoperative value at the last follow-up, patients were categorized into two groups: PJK and non-PJK, with 21 and 95 patients respectively.

## Statistical Analysis

Statistical analysis was performed with IBM SPSS Statistics v.21.0 (IBM Corp., Armonk, New York, USA). For changes in radiographic parameters, a Paired t tests was used and for differences between categorical variables, an independent t test was used. Pearson correlation coefficient (r) was used to establish relationships between potential risk factors and developing PJK. Statistical significance was defined as  $P < 0.05$ .

## Results

Among the 96 patients with a mean age of 14.00 years ( $\pm 0.82$ ), the overall incidence of PJK was 22%. Fused levels was similar in patients with and without PJK ( $9.95 \pm 1.91$  vs.  $9.05 \pm 1.72$ ,  $p = 0.059$ ), meanwhile no statistical differences in the preoperative main Cobb, ages, gender, Risser, preoperative and postoperative PJA were observed between the two groups ( $P > 0.05$ , *Table 1*).

Comparisons between preoperative and immediate postoperative values in PT, SS, LL, TK and SVA reveal significant differences ( $P < 0.05$ , *Table 2*), while the PI showed no significant change after surgery ( $P = 0.079$ ). No statistical difference were demonstrated between PJK and non-PJK group at the preoperative, postoperative, and final follow-up in the sagittal parameters of PI, PT, and TK ( $P > 0.05$ , *Table 3*). PJK group showed a significantly greater preoperative SVA than non-PJK group ( $P = 0.032$ ). At the last follow-up, PJK patients had significantly greater LL ( $P = 0.046$ ). Meanwhile, PJK experienced larger correction of SVA ( $P = 0.007$ , *Table 3*).

Patients in the PJK group had significantly greater preoperative PJA-RCA than the non-PJK group ( $4.07 \pm 3.30$  vs.  $1.42 \pm 4.28$ ,  $P = 0.024$ , *Table 1*). However, RCA was not significantly different between two groups ( $3.88 \pm 4.34$  vs.  $2.86 \pm 3.36$ ,  $P = 0.405$ ). In addition, Pearson correlation coefficient showed a significant correlation between the change of SVA and the last follow-up PJA ( $r = -0.208$ ,  $P = 0.042$ ). The changes in TK and LL were revealed no significant correlation with the last follow-up PJA. Otherwise, preoperative PJA-RCA and postoperative PJA-RCA demonstrated similar results which showed a strong correlation with the last follow-up PJA ( $r = 0.528$  and  $r = 0.532$  respectively,  $P < 0.000$ , *Table 4*).

## Discussion

PJK rate in this study was 22% with a minimum 1.5-year and average 2-year follow-up. In terms of timing, most patients (71.4%) occurred PJK within 1.5 years, which was similar to Wang et al (80%). [7] Kim et al [4] analysed PJK in 410 consecutive patients, and most patients (70%) had this pathology at the 2-year follow-up. The above evidence may indicate that PJK mainly occurred within the year of 1.5 or 2 after surgery. We defined PJK as the Cobb angle between the UIV and the UIV<sub>2</sub> is 10° or greater, and at least 10° greater than the preoperative value. [6] However, due to the inconsistent definitions, the incidence of PJK could vary hugely. In a 1999 study by Lee et al [12], the authors used 5° as the cutoff value and the incidence of PJK was 46%. Helgeson et al [5] measured the Cobb angle between the UIV and the UIV<sub>1</sub>, and redefined PJK as any postoperative kyphosis increase  $\geq 15^\circ$ . The incidence of PJK was 8.1% in their pedicle screws group. Thus, a consensual and precise definition of PJK is needed in the further study.

As shown by the current data, we found greater preoperative PJA-RCA in PJK group, a strong correlation between PJA-RCA and the last follow-up PJA, but no significant difference in RCA between PJK and non-PJK group which showed the contrary result with Lonner et al [11]. The reason might be that decreased RCA reflects an absolute straight rod curve while greater PJA-RCA means a relative straight rod curve. Moreover, they found RCA was a risk factor for PJK in Lenke 2 and 4 curves, but our object included other curve types. Theoretically, improper rod contouring would reciprocally change the biomechanical forces in proximal junctional part. A biomechanical study reported that the increase of the sagittal rod curvature from 10° to 20°, 30°, and 40° increased the proximal junctional angle (PJA) (by 6%, 13%, and 19%) and the proximal flexion force (3%, 7%, and 10%) and moment (9%, 18%, and 27%), [13] indicating that absolute increased RCA may be also associated with PJK. Therefore, the risk factor of “relative straight rod curve” would be more convincing. According to Dubousset’s concept of “cone of economy”, the spine alignment tends to balance itself in all three dimensions with minimal energy. Before the operation, AIS patient’s body has experienced self-compensation to adapt to spine misalignment. When the spine alignment is corrected and changed, there will be a rebalance. In case of maintaining a similar compensation in junctional area, mismatched rod curve would be easier to create a vertebral angulation, (Fig. 3, A  $\approx$  B) which could result in PJK further. Consequently, proper rod contouring should be seriously taken into consideration during the AIS spinal surgery.

The etiologies of PJK are multifactorial. In particular, residual sagittal imbalance and greater curvature correction were previously revealed as potential risk factors for PJK. [4, 8, 9, 11] In this study, PJK group showed a significantly greater preoperative SVA ( $P = 0.032$ ) and larger correction of SVA ( $P = 0.007$ , Table 3), demonstrating PJK patients experienced a sagittal imbalance and overcorrection. Meanwhile, to form a kind of mutual compensation mechanism, the sagittal parameters of TK, LL and SVA significantly increased at the final follow-up, showing a resilient trend. (Table 5) It will aggravate this trend when the sagittal imbalance is severe. At the last follow-up, PJK patients had significantly greater LL. A recent meta-analysis [9] similarly reported that larger preoperative TK, larger preoperative and postoperative LL, greater TK change, and greater LL change were identified as risk factors for PJK in AIS. Meanwhile, some studies have demonstrated that PJK might be a compensation mechanism rather than complication

when spine is shifted and overcorrected.[8, 14, 15] The results remind orthopaedic surgeons should better avoid overcorrection and estimate the probability of PJK occurring when making a big angle correction operation.

Equally important, spinopelvic parameters have proved to be predictive of PJK. Kim et al[16] reported that patients requiring revision for PJK had a LL that was closer to the PI and patients without PJK had a LL much lower than the PI in adult spinal deformity. Ferrero et al[8] found that AIS patients with high pelvic incidence were more at risk of PJK. In contrast to these studies, we found no statistical difference in PI. Besides, other surgically controllable PJK risk factors such as UIV caudal to the proximal UEV (Lenke 1), UIV cephalad to the UEV or at lower thoracic levels and disruption of junctional ligaments (Lenke 5)[11, 17] should not be overlooked by surgeons in the preoperative planning process.

There were some limitations in our study. First limitation of this study was its retrospective nature. Second, the number of cases was small and we did not categorize the type of AIS curves. Third, there was a lack of evaluation to muscle condition and junctional ligaments at the proximal junctional area, methods similar to the study about adult spinal deformity [18] is needed. Moreover, further analysis based on the classification of AIS curves and a larger number of samples are necessary. Finally, we did not reach a specific value of PJA-RCA which could be used as a standard threshold to prevent PJK.

## Conclusions

As a new definition, large PJA-RCA means a relative improper rod contouring, and could be regarded as a risk factor for PJK in AIS. The etiology of PJK might be a kind of compensation mechanism rather than a complication when spine is shifted and overcorrected.

## List Of Abbreviations

AIS, adolescent idiopathic scoliosis; PJK, proximal junctional kyphosis; PJA, proximal junctional angle; PJF, proximal junctional failure; RCA, rod contouring angle; PJA-RCA, difference between PJA and RCA; UIV, upper instrumented vertebra; PI, pelvic incidence; PT, pelvic tilt; TK, thoracic kyphosis; LL, lumbar lordosis; SVA, sagittal vertical axis

## Declarations

## Ethics approval and consent to participate

This retrospective study was approved by the Ethics Committee of the First Affiliated Hospital of Zhengzhou University. The consent has been received from the parents of the adolescence featured in this study.

## Consent to publication

Not applicable.

## Availability of data and material

This article is a clinical retrospective study, and all relevant data are within the paper. The raw datasets used and/or analyzed during this study are available from the corresponding author on reasonable request

## Competing interests

The authors declare that they have no competing interests.

## Funding

The authors declare that they have no funding sources.

## Authors' contributions

JW and NNY contributed to the conception. JW, ML, and NNY contributed to the designs and the draft of the work and revised it critically for important intellectual content. JW and NL did the acquisition and analysis of the data. JW and NNY revised this study critically for important intellectual content. JW and YGF approved the version to be published. All authors read and approved the final manuscript.

## Acknowledgements

All authors were directly involved in the entire process

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## Tables

**Table 1.** Demographic and radiographic data between the two groups

Variable	PJK Group (n=21)	Non-PJK Group (n=75)	<i>P</i> value
Age, years	14.48±1.50	14.62±1.28	0.759
Gender, n (%female)	15(71.43)	52(69.33)	0.541
Risser 4/5, n (%)	8(38.10)	26(34.67)	0.423
Preoperative main Cobb ( °)	51.53±3.70	49.70±4.99	0.192
No. of level fused	9.95±1.91	9.05±1.72	0.059
RCA	3.88±4.34	2.86±3.36	0.405
Preoperative PJA	7.76±4.16	5.95±4.48	0.122
Postoperative PJA	6.65±4.15	4.60±4.01	0.150
Follow-up PJA	22.35±5.71	7.28±5.09	<b>≪0.0001*</b>
preoperative PJA-RCA	4.07±3.30	1.42±4.28	<b>0.024*</b>
postoperative PJA- RCA	2.96±2.96	2.75±4.05	0.821

**Table 2.** Comparison between preoperative and postoperative sagittal parameters in all patients

Variable	Preoperative	Postoperative	<i>P</i> value
PI	46.00±9.27	47.37±9.53	0.079
PT	11.28±6.44	12.60±6.41	<b>0.030*</b>
TK	22.89±8.94	18.01±6.04	<b>0.0001*</b>
LL	51.20±10.92	42.95±11.83	<b>0.0001*</b>
SVA	29.16±26.38	13.15±22.22	<b>0.0001*</b>

**Table 3.** Comparison of sagittal parameters between the two groups

Variable	PJK Group (n=21)	Non-PJK Group (n=75)	<i>P</i> value
Preoperative parameters			
PI	48.15±10.09	48.94±10.54	0.823
PT	11.51±6.82	10.55±6.69	0.610
TK	23.91±9.04	22.81±9.33	0.706
LL	54.04±12.42	52.89±9.88	0.772
SVA	40.19±21.57	20.55±30.05	<b>0.032*</b>
Postoperative parameters			
PI	47.28±8.48	46.36±9.72	0.757
PT	11.55±7.03	13.33±7.61	0.465
TK	15.91±6.43	17.60±6.23	0.439
LL	43.71±9.19	42.48±13.04	0.758
SVA	16.16±18.39	9.35±26.60	0.388
ΔSVA	-24.03±17.80	-11.21±14.74	<b>0.007*</b>
ΔTK	-8.01±7.69	-5.22±6.88	0.215
ΔLL	-10.33±11.60	-10.41±9.84	0.977
Follow-up parameters			
PI	50.06±12.10	46.90±7.95	0.287
PT	13.63±6.82	11.56±5.58	0.319
TK	25.74±9.79	19.80±8.35	0.071
LL	55.20±11.90	47.56±9.45	<b>0.046*</b>
SVA	22.23±22.71	6.12±28.34	0.084

**Table 4.** Correlation analysis between change in the last follow-up PJA and variables

Variable	Follow-up PJA	
	Coefficient	<i>P</i> value
Preoperative PJA-RCA	0.528	<b>¶0.0001*</b>
Postoperative PJA-RCA	0.532	<b>¶0.0001*</b>
ΔTK	-0.151	0.141
ΔSVA	-0.208	<b>0.042*</b>
ΔLL	0.061	0.556

**Table 5.** Comparison between postoperative and other sagittal parameters in PJK group

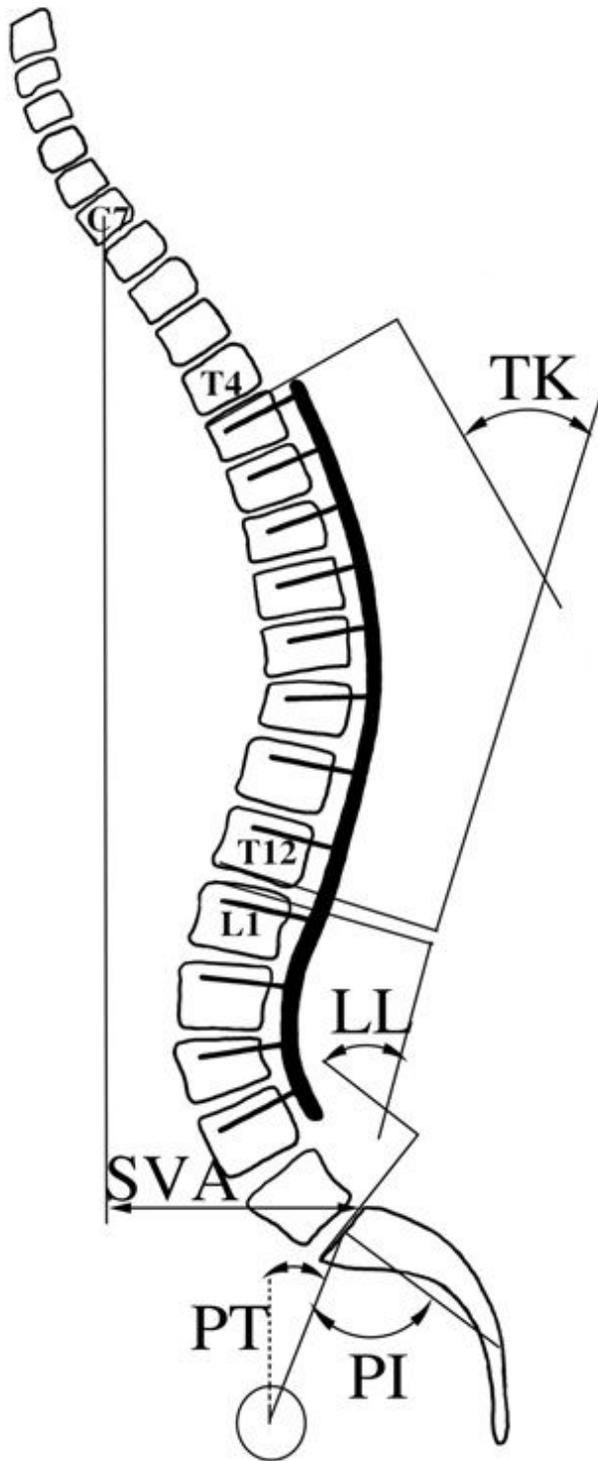
Variable	Preoperative	Postoperative	<i>P</i> value	Follow-up	<i>P</i> value
PT	11.51±6.82	11.55±7.03	0.982	13.63±6.82	0.223
TK	23.91±9.04	15.91±6.43	<b>¶0.0001*</b>	25.74±9.79	<b>¶0.0001*</b>
LL	54.04±12.42	43.71±9.19	<b>0.001*</b>	55.20±11.90	<b>¶0.0001*</b>
SVA	40.19±21.57	16.16±18.39	<b>¶0.0001*</b>	22.23±22.71	<b>0.025*</b>

## Figures



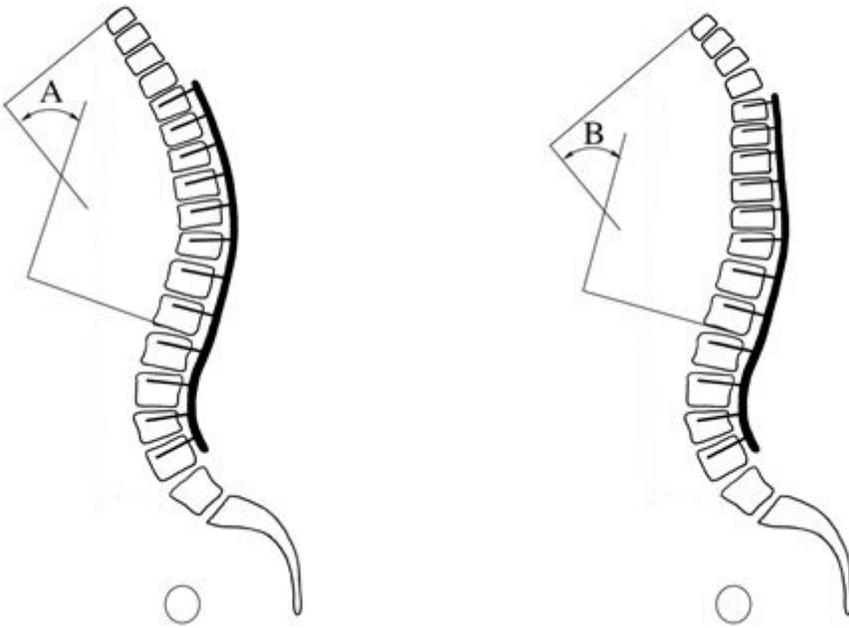
**Figure 1**

The measurement of proximal junctional kyphosis (PJK) and rod contouring angles (RCA).



**Figure 2**

Pelvic and Spinal parameters: pelvic incidence (PI), pelvic tilt (PT), T5-T12 thoracic kyphosis (TK), lumbar lordosis (LL) and sagittal vertical axis (SVA).



**Figure 3**

Compensatory angulation:  $A \approx B$ .