

# Incidence, Risk Factors, and Prevention Strategy for Proximal Junctional Kyphosis in Adult Spinal Deformity Surgery

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## Abstract:

**Introduction:** Proximal junctional kyphosis (PJK) is an acute complication of adult spinal deformity (ASD) surgery and may require re-operation because of proximal junctional failure (PJF). PJK causes and prevention strategies remain unknown. This study aimed to investigate the differences in the backgrounds of patients with PJK, compared to those without PJK, in ASD surgery.

**Methods:** We included data from 86 patients who underwent ASD surgery between 2012 and 2018. There were 40 patients (46.5%) with PJK; 46 patients did not have PJK until the last follow-up. We evaluated patient demographics, clinical outcomes, and radiographic parameters, such as Cobb angle and spinopelvic parameters on standing X-ray films, in each group.

**Results:** There was no significant difference in patient demographics, clinical outcomes, or preoperative radiographic parameters. Postoperative pelvic incidence minus lumbar lordosis (PI-LL) and pelvic tilt (PT) were significantly lower in the PJK group, and thoracic kyphosis (TK) was higher. The cutoff values were 34.5° for TK, 0.5° for PI-LL, and 15.5° for PT. Other radiographic parameters were not significantly different. PJF developed in seven patients (17.5%) in the PJK group. PJF patients had significantly older age, higher postoperative TK, higher postoperative proximal junctional Cobb angle (PJA), more changes between pre- and postoperative PJA, and lower satisfaction scores on the Scoliosis Research Society Outcomes Questionnaire (SRS-22 satisfaction) than non-PJF patients in the PJK group.

**Conclusions:** One risk factor for PJK was lower postoperative PI-LL that was 0° or less. In ASD surgery, the most critical factor in a PJK prevention strategy is to obtain a postoperative LL adjusted by PI, which is >0°.

## Keywords:

adult spinal deformity, proximal junctional kyphosis, spinopelvic parameters, prevention strategy

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## Introduction

Thoracic and lumbar kyphosis and/or scoliosis are adult spinal deformities (ASD) that presented with abnormal posture, and intermittent claudication for back and leg pain leading to worsening quality of life (QOL). ASD patients receive conservative treatment at first; however, for those patients who experience QOL decline, surgical treatment is an option<sup>1)</sup>.

On the other hand, ASD surgery is associated with many

complications and the need for re-operations. Proximal Junctional Kyphosis (PJK) occurs at a high rate of 20% to 40% in ASD surgery and may require re-operation. Re-operation because of PJK is called proximal junctional failure (PJF), which causes serious problems, such as implant protrusion and paralysis, with a worse clinical course<sup>2,3)</sup>.

In recent years, progress in surgical techniques, such as a three-column osteotomy (e.g., pedicle subtraction osteotomy or vertebral column resection) and Lateral Interbody Fusion (LIF), have led to better corrective results<sup>4,5)</sup>. Still, the inci-

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**Table 1.** Patient Demographics of PJK and Non-PJK Groups.

	PJK (+)	PJK (-)	p-value
Sex (M:F)	4:36	3:43	0.860
Age (year)	67.1±7.5	67.9±7.4	0.680
Follow-up (month)	50.4±18.2	53.4±17.5	0.394
Young adult mean (%)	73.0±12.4	75.2±10.4	0.328
Operative time (minute)	589.9±150.1	634.8±185.6	0.337
Operative blood loss (ml)	1078.9±660.2	1227.3±793.6	0.489
Surgical method (AP:P)	32:8	34:12	0.508
Fusion level (UT:LT)	13:27	20:26	0.299

Values are mean (±standard deviation). PJK: proximal junctional kyphosis, AP: anterior-posterior surgery, P: posterior surgery, UT: upper thoracic, LT: lower thoracic

dence of PJK has not improved. There are various causes of PJK, and different PJK/PJF prevention strategies, but these strategies are ineffective<sup>2,3,6</sup>. Previous reports have shown positive outcomes of ASD surgery<sup>7,8</sup>, but there are no PJK prevention guidelines. This study aimed to investigate the differences in the backgrounds of patients with PJK compared to those without PJK.

### Materials and Methods

We retrospectively reviewed a database from April 2012 to March 2018 from a single institution. We included ASD patients with the following criteria: 1) aged more than 50 years at the time of surgery, 2) pelvic incidence minus lumbar lordosis (PI-LL) >10°, 3) sagittal vertical axis (SVA) >4 cm, 4) pelvic tilt (PT) >20°, 5) upper instrumented vertebra (UIV) above T10, 6) S2 alar iliac screws placed distal to the sacropelvic fixation, and 7) follow-up for at least two years. Exclusion criteria were infection, tumor, and cases that did not require spinal deformity correction. One hundred eight patients who had undergone reconstruction surgery were screened and 86 (79.6%) were finally enrolled. Through the last follow-up, we defined 40 patients (46.5%) with PJK and 46 patients without PJK through.

Patient demographics were collected, including age, sex, young adult mean of the femoral neck, operative time, operative blood loss, surgical methods with or without LIF, and fusion level (upper thoracic or lower thoracic). Clinical outcomes were assessed with the Oswestry Disability Index (ODI) and satisfaction score of the Scoliosis Research Society Outcomes Questionnaire (SRS-22 satisfaction) two years postoperatively.

Radiographic parameters, including coronal Cobb angle, thoracic kyphosis (TK), lumbar lordosis (LL), PI-LL, PT, and SVA pre- and postoperatively, and at the final follow-up, were measured.

PJK is a proximal junctional Cobb angle (PJA) ≥10° and PJA at least 10° higher than the preoperative measurement<sup>9</sup>. PJK was evaluated from standing X-ray films immediately after surgery, one year postoperatively, and during the last follow-up. PJF is the requirement for a re-operation in a

**Table 2.** Radiographic Parameters of PJK and Non-PJK Groups.

	PJK (+)	PJK (-)	p-value
<b>Preoperative</b>			
Cobb angle (°)	49.9±13.5	49.3±12.9	0.682
TK (°)	20.6±19.4	15.7±16.0	0.443
LL (°)	6.3±24.3	7.8±19.6	0.762
PI-LL (°)	41.2±22.4	46.8±18.4	0.133
PT (°)	31.9±9.6	34.3±10.2	0.332
SVA (cm)	11.1±5.6	12.3±6.9	0.359
<b>Postoperative</b>			
Cobb angle (°)	15.7±6.4	17.0±11.0	0.938
TK (°)	35.0±11.0	28.0±9.4	0.004*
LL (°)	50.6±10.5	47.9±10.6	0.290
PI-LL (°)	-2.5±11.2	5.7±11.2	0.002*
PT (°)	17.0±8.5	21.2±7.5	0.020*
SVA (cm)	3.2±2.4	3.0±3.9	0.260
<b>Changes</b>			
Cobb angle (°)	-34.2±10.0	-32.3±11.0	0.548
TK (°)	14.7±18.7	12.3±13.1	0.248
LL (°)	44.3±21.7	40.2±16.6	0.307
PI-LL (°)	-43.7±20.5	-41.1±16.1	0.579
PT (°)	-15.0±7.2	-12.0±14.3	0.356
SVA (cm)	-8.0±4.4	-7.5±12.2	0.581
<b>Final follow up</b>			
Cobb angle (°)	15.4±6.9	15.8±9.3	0.960
TK (°)	42.7±14.3	30.5±9.4	0.001*
LL (°)	45.1±12.4	45.3±9.7	0.958
PI-LL (°)	2.8±12.8	8.3±12.4	0.038*
PT (°)	22.1±8.0	24.3±9.7	0.296
SVA (cm)	4.7±3.8	3.8±4.8	0.136

Values are mean (±standard deviation). \* indicates a significant difference between groups. PJK: proximal junctional kyphosis, °: degree, TK: thoracic kyphosis, LL: lumbar lordosis, PI: pelvic incidence, PT: pelvic tilt, SVA: sagittal vertical axis

PJK patient.

Statistical analysis was performed using SPSS software (IBM SPSS Inc, Version 26.0; Armonk, NY: IBM Corp). The p-values were based on Student's t-tests or Mann-Whitney tests, depending upon the normal distribution of data. The p-values < 0.05 were considered significant.

### Results

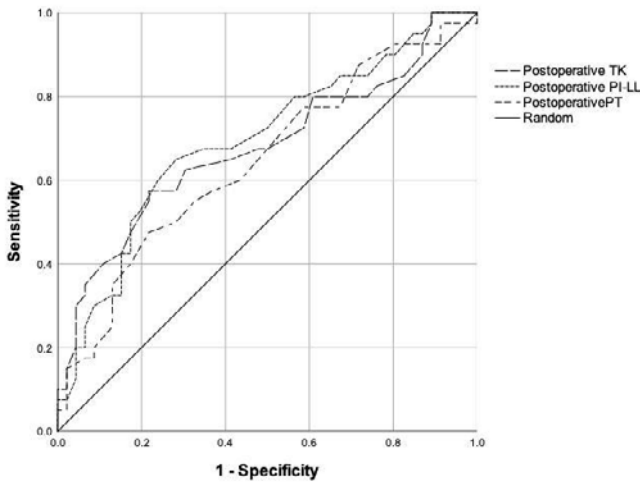
We analyzed patient demographics analyzed for each group, as shown in Table 1. Demographic data were not significantly different between groups. PJK occurred immediately after surgery in 27 of 40 patients (67.5%). PJK was observed in 36 patients (90.0%) one year postoperatively, and 40 patients (100%) by the final follow-up.

Table 2 presents the preoperative, postoperative, and final follow-up radiographic parameters for each group. There were no differences between groups for preoperative radiographic parameters.

Postoperatively, TK was significantly higher in the PJK

group ( $35.0^\circ$  vs.  $28.0^\circ$ ,  $p=0.004$ ), PI-LL was significantly lower in the PJK group ( $-2.5^\circ$  vs.  $5.7^\circ$ ,  $p=0.002$ ), and PT

was significantly lower ( $17.0^\circ$  vs.  $21.2^\circ$ ,  $p=0.020$ ) in the PJK group. Other postoperative radiographic parameters were not significantly different. Receiver operating characteristic (ROC) curves obtained postoperatively (Fig. 1) were used to determine cutoff values for TK ( $34.5^\circ$ ), PI-LL ( $0.5^\circ$ ), and PT ( $15.5^\circ$ ). The area under the ROC curve (AUC) of PI-LL (0.697) was larger than for TK (0.678) and PT (0.646).



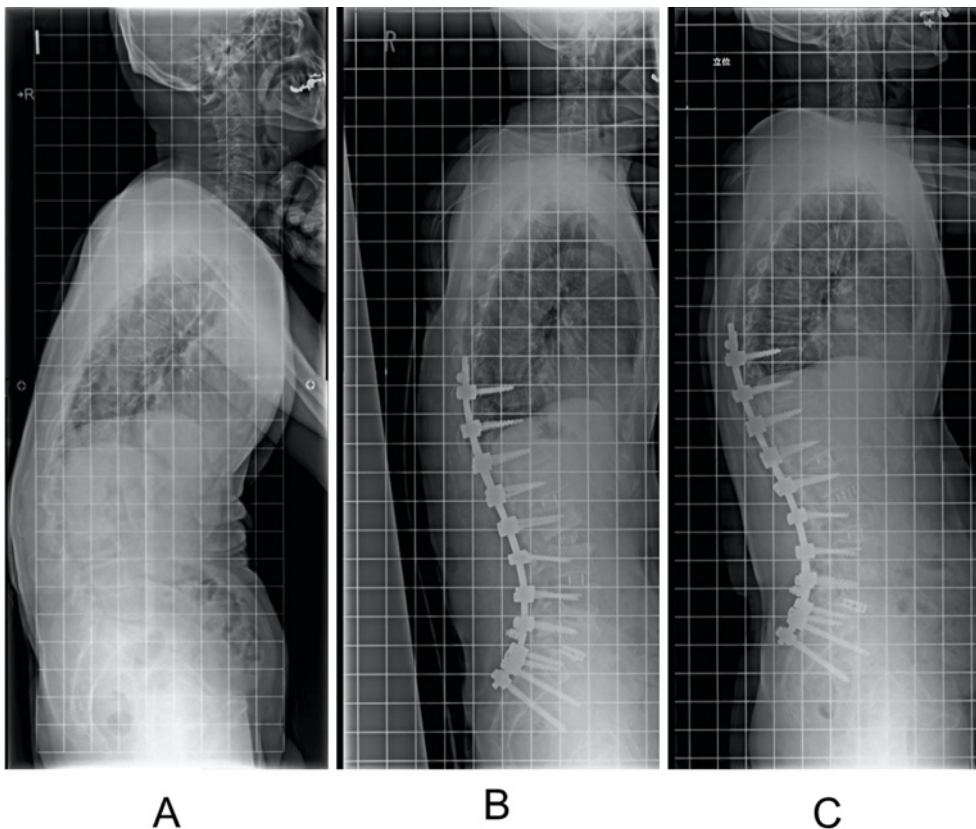
**Figure 1.** Figure 1 shows the ROC curves for postoperative PI-LL, TK, and PT. The cutoff values for TK ( $34.5^\circ$ ), PI-LL ( $0.5^\circ$ ), and PT ( $15.5^\circ$ ) were determined by the largest angle of “sensitivity - (1 - specificity)”. The AUC of PI-LL ( $0.697\pm0.057$ ) was larger than for TK ( $0.678\pm0.059$ ) and PT ( $0.646\pm0.060$ ).

The changes between pre- and postoperative radiographic parameters were not significantly different within the groups.

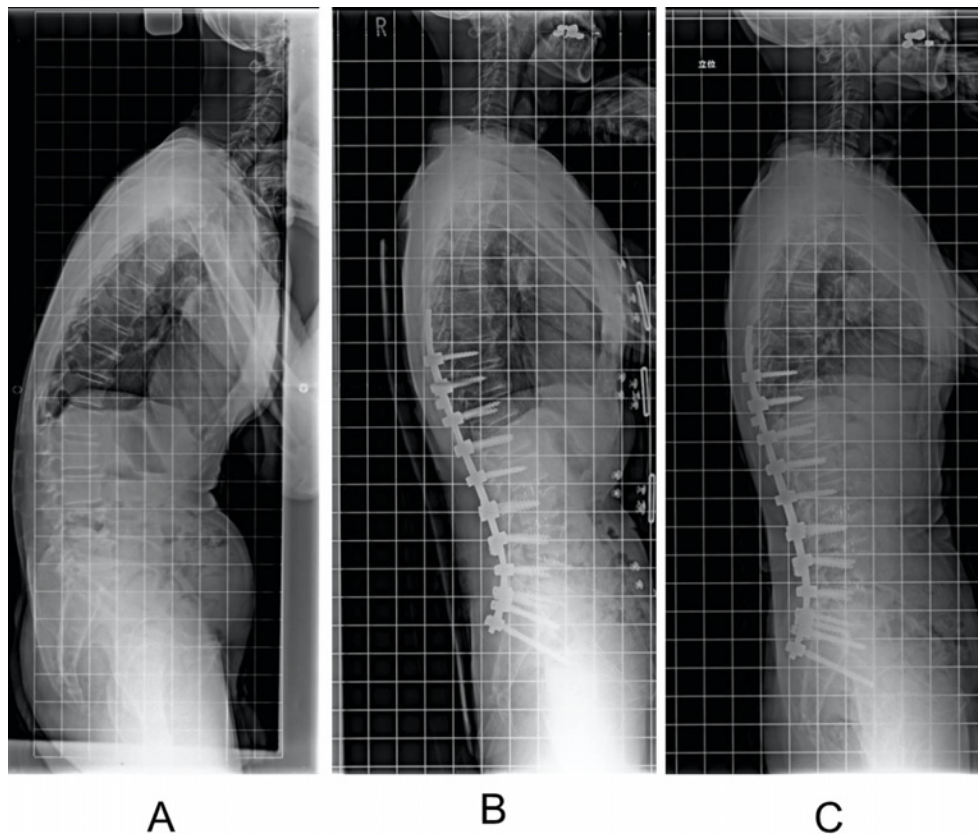
At the last follow-up, TK was significantly higher ( $42.7^\circ$  vs.  $30.5^\circ$ ,  $p=0.001$ ), and PI-LL ( $2.8^\circ$  vs.  $8.3^\circ$ ,  $p=0.038$ ) was significantly lower, in the PJK group. Other parameters were not significantly different (Fig. 2, 3).

ODI and SRS-22 satisfaction were used to evaluate clinical outcomes at the final follow-up. ODI ( $1.5\pm0.9$  vs.  $1.2\pm0.9$ ,  $p=0.252$ ) and SRS-22 satisfaction ( $3.7\pm0.5$  vs.  $3.7\pm0.7$ ,  $p=0.403$ ) were similar in both groups.

PJF developed in seven patients (17.5%) in the PJK group. One patient required hook removal and cutting of the rods. Six patients required upper thoracic spine extension caused by a burst fracture at the UIV. The UIV of all six patients who required extension was in the thoracolumbar re-



**Figure 2.** A 62-year-old man presented with ASD (PJK group). (A) Preoperative X-rays revealed severe spinopelvic imbalance with PI-LL= $40^\circ$ , PT= $31^\circ$ , and SVA= $14.2$  cm. (B) Although spinopelvic parameters had been corrected to PI-LL of  $-9^\circ$ , PT of  $17^\circ$  and SVA= $2.4$  cm 2 weeks after surgery. PJK developed with PJA= $17^\circ$  and a postoperative increase of  $12^\circ$  after surgery. (C) At the most recent observation (4 years postoperatively), although there was no complaint, PJA had mildly progressed to  $22^\circ$ .



**Figure 3.** A 74-year-old man presented with ASD (non-PJK group). (A) Preoperative X-rays revealed severe spinopelvic imbalance with PI-LL=48°, PT=33°, and SVA=17.6 cm. (B) Spinopelvic parameters had been corrected to PI-LL of 2°, PT of 26°, and SVA=-3.6 cm 2 weeks after surgery. PJA was 14° but increased postoperatively by 7°. (C) At the most recent observation (3 years postoperatively), PJA had increased only 3° compared with preoperative values.

gion in the initial surgery. Table 3 presents patient demographics analyzed for PJF and non-PJF patients in the PJK group. PJF patients had a significantly older age (72.9 years vs. 65.9 years,  $p=0.016$ ) than non-PJF patients in the PJK group. Table 4 presents preoperative, postoperative, and postoperative changes radiographic parameters analyzed for each group. PJF patients had significantly higher postoperative TK (44.0° vs. 33.1°,  $p=0.019$ ), higher postoperative PJA (22.6° vs. 13.8°,  $p=0.004$ ), and greater changes between pre- and postoperative PJA (19.7° vs. 11.0°,  $p=0.002$ ) than non-PJF patients in the PJK group. Clinical outcomes at the final follow-up analyzed for each group. PJF patients had significantly lower SRS-22 satisfaction (2.9±0.3 vs. 3.8±0.7,  $p=0.018$ ) than non-PJF patients in the PJK group. The ROC curves (Fig. 4) indicated cutoff values for age (70.5 years), postoperative TK (38.5°), postoperative PJA (15.5°), and postoperative PJA changes (14.5°). The AUC of postoperative PJA changes (0.870) was larger than for postoperative PJA (0.851), age (0.792), and postoperative TK (0.786).

## Discussion

PJK is one of the most common complications of adult spinal deformity surgery, with an incidence of 20% to 40%; 13% to 66% of those require re-operation because of PJF<sup>2,3</sup>.

PJF requiring re-operation may cause fracture or paralysis. Our results were similar to those reported by others. Both patient and operative factors account for this, but PJK is a multifactorial complication, and effective prevention strategies are unproven.

The major risk factors for PJK are older age, severe deformities, higher correction, anterior-posterior spinal fusion, and fusion to the sacrum<sup>2,3,6</sup>. Minor risk factors are low bone density, high BMI, and the presence of comorbidities<sup>2,3,6</sup>.

Our results indicated that lower postoperative PI-LL was the highest risk factor for PJK. To emphasize, the number of PJK patients with PI-LL≤0° increased postoperatively. These results indicate that it is important to obtain postoperative LL that matches the PI. It reduces the mechanical stress on the proximal junction and thus the risk of PJK. Of the seven patients with PJF, five patients had postoperative PI-LL≤0°. At one time, it was difficult to achieve a large LL for severe deformities through surgery. In recent years, a large LL could be obtained by three-column osteotomy and LIF, but excessive LL causes PJK as an overcorrection. Other PJK prevention strategies were to achieve a postoperative TK≤34.5°, and postoperative PT≥15.5°. However, TK was not included in the fixation area in the case with UIV in the lower thoracic spine, and PT could not be confirmed intraoperatively. LL could be confirmed intraoperatively. If

**Table 3.** Patient Demographics of PJF and Non-PJF Patients in the PJK Group.

	PJF (+)	PJF (-)	p-value
Sex (M:F)	1:6	3:30	0.459
Age (year)	72.9±3.6	65.9±7.5	0.016*
Follow-up (month)	42.9±15.2	52.0±18.4	0.206
Young adult mean (%)	75.2±17.2	72.5±11.1	0.856
Operative time (minute)	529.4±116.0	602.7±153.3	0.463
Operative blood loss (ml)	817.3±542.8	1134.4±669.5	0.180
Surgical method (AP:P)	7:0	25:8	0.326
Fusion level (UT:LT)	1:6	12:21	0.382

Values are mean (±standard deviation). \* indicates a significant difference between groups. PJF: proximal junctional failure, PJK: proximal junctional kyphosis, AP: anterior-posterior surgery, P: posterior surgery, UT: upper thoracic, LT: lower thoracic

the appropriate postoperative PI-LL was obtained, postoperative PT also had an appropriate value in many cases. It is important to obtain the postoperative LL adjusted by PI (the postoperative PI-LL) greater than 0°.

PJK occurred immediately after surgery in 27 of 40 patients (67.5%) and increased to 36 patients (90.0%) one year after the operation. Yagi et al. showed that 66% of PJK patients could be identified within three months after surgery<sup>10</sup>. Our results are consistent with this. The overload at the UIV level causes PJK earlier.

PJF was caused by a vertebral fracture and/or the posterior ligament complex at UIV level<sup>2,3</sup>. Patients with PJF may require re-operation because of pain, skin troubles, neurological deficits, or ambulatory difficulties<sup>2,3</sup>. The PJA was increased by 20° or more with PJF<sup>3</sup>. A standing X-ray in patients with PJF showed that PJA increased about 20° in the immediate postoperative period and then progressed to PJF. In our sample population, seven patients with PJF had significantly older age, higher postoperative TK, higher postoperative PJA, and greater changes in pre- and postoperative PJA than non-PJF patients in the PJK group. In addition to these, excessive correction of postoperative PI-LL ≤ 0° may increase the risk of PJF. Of the seven patients with PJF, PI-LL was 0° or less in five patients and PI-LL was -10° or less in three patients. The UIV of six of the seven patients with PJF who required extension because of a burst fracture was in the lower thoracic spine in the initial surgery. Although there was no significant difference in the selection of the UIV, the risk of PJF was greater if postoperative TK was 38.5° or more. Therefore, extending the UIV to the upper thoracic spine to lower postoperative TK at the initial surgery is a desirable goal to prevent PJF.

In our results, ODI and SRS-22 satisfaction were similar in both groups. Because the PJK was evaluated radiographically, even if the PJK was positive, no symptoms were recognized. The correlation between QOL and radiographic parameters emphasizes the importance of global sagittal balance and spinopelvic parameters<sup>7</sup>. One of these parameters is the LL proportional to the PI, and the LL should be in-

**Table 4.** Radiographic Parameters of PJF and Non-PJF Patients in the PJK Group.

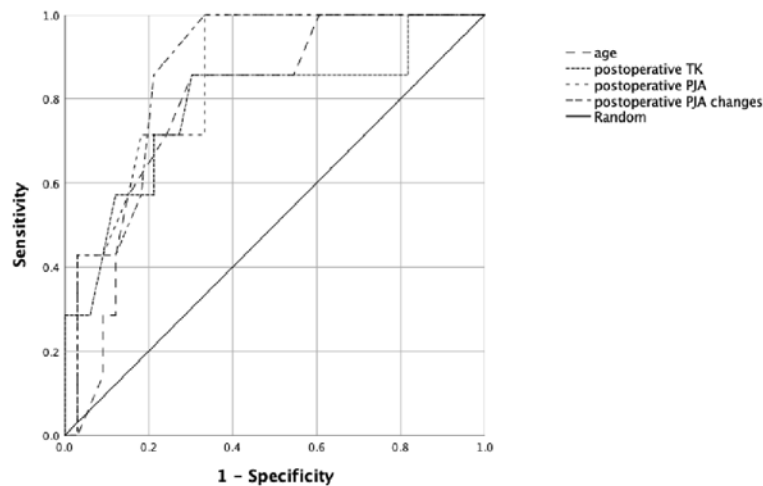
	PJF (+)	PJF (-)	p-value
Preoperative			
Cobb angle (°)	47.5±12.8	50.2±13.6	0.681
TK (°)	19.7±9.1	20.8±20.9	0.640
LL (°)	-0.6±8.4	7.8±26.2	0.364
PI-LL (°)	39.0±6.9	41.7±24.5	0.789
PT (°)	31.3±9.2	32.1±9.7	0.783
SVA (cm)	9.6±2.7	11.4±6.0	0.498
PJA (°)	2.9±4.6	2.8±5.0	0.680
Postoperative			
Cobb angle (°)	10.8±4.7	16.4±6.3	0.153
TK (°)	44.0±11.5	33.1±9.8	0.019*
LL (°)	46.4±10.3	51.5±10.4	0.363
PI-LL (°)	-5.3±12.6	-1.8±10.8	0.569
PT (°)	16.7±7.5	17.1±8.7	0.831
SVA (cm)	2.8±2.3	3.3±2.4	0.735
PJA (°)	22.6±6.1	13.8±6.4	0.004*
Changes			
Cobb angle (°)	-23.8±12.4	-33.8±9.5	0.612
TK (°)	24.3±8.4	12.3±19.3	0.067
LL (°)	47.0±10.4	43.7±23.3	0.618
PI-LL (°)	-44.3±10.6	-43.5±22.0	0.972
PT (°)	-14.6±8.0	-15.1±7.0	0.769
SVA (cm)	-6.8±3.3	-8.2±4.6	0.510
PJA (°)	17.5±2.4	11.3±7.9	0.002*

Values are mean (±standard deviation). \* indicates a significant difference between groups. PJF: proximal junctional failure, PJK: proximal junctional kyphosis, °: degree, TK: thoracic kyphosis, LL: lumbar lordosis, PI: pelvic incidence, PT: pelvic tilt, SVA: sagittal vertical axis, PJA: proximal junctional angle

creased to PI±9. Our strict standard for PJK prevention was that the postoperative LL adjusted by PI should be greater than 0°. PJF patients in the PJK group had significantly lower SRS-22 satisfaction so it is important not to create PJK in order not to cause PJF secondary to PJK, especially in cases with 70 years old or older.

Preoperative planning and intraoperative evaluation are necessary to obtain the ideal postoperative PI-LL as a preventive strategy for PJK and PJF. Preoperative full spine X-rays in the prone position and fulcrum backward bending are useful to evaluate the required correction angle. If two-stage surgery is possible, further evaluation can be made after the first operation. In some cases, it is possible to change the surgical plan to extend the fixation level to prevent the PJK and PJF before the second operation. The use of an intraoperative computer-assisted device is effective in preventing under- or overcorrection and can reduce the operative time. Intraoperative X-rays are most important to determine whether the ideal postoperative PI-LL has been obtained.

There are some limitations of this study. First, this is a retrospective study with small sample size. Other factors may be identified as the number of cases increases. Second, there may be other risk factors than those investigated here.



**Figure 4.** Figure 4 shows the ROC curves for age, postoperative TK, postoperative PJA, and postoperative PJA changes. The cutoff values for age (70.5 years), postoperative TK (38.5°), postoperative PJA (15.5°), and postoperative PJA changes (14.5°) were determined by the largest angle of “sensitivity - (1 - specificity)”. The AUC of postoperative PJA changes (0.870±0.058) was larger than for postoperative PJA (0.851±0.066), age (0.792±0.081), and postoperative TK (0.786±0.107).

Further prospective studies are needed to validate our results.

## Conclusion

Our results showed that 40 of 86 patients (46.5%) who underwent ASD surgery had PJK. Of those 40, 27 patients (67.5%) had PJK immediately after surgery, and 36 patients (90.0%) had PJK within one year postoperatively. PJF required re-operation in 7 of 40 patients (17.5%). The risk factors for PJK were higher postoperative TK and lower postoperative PI-LL and PT. In ASD surgery, the most important factor for a PJK prevention strategy was to maintain a postoperative PI-LL >0°.

**Conflicts of Interest:** The authors declare that there are no relevant conflicts of interest.

**Ethical Approval:** No. 2020007, Institutional review board of Seirei Sakura Citizen Hospital.

**Author Contributions:** Tsuyoshi Sakuma wrote and prepared the manuscript, and all of the authors participated in the study design. All authors have read, reviewed, and approved the article.

**Informed Consent:** Informed consent was obtained by all participants in this study.

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