

Risk Factors for Proximal Junctional Kyphosis in Fusions from the Sacrum to L1 or L2 for Adult Spinal Deformity

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Abstract:

Introduction: Several targets have been proposed to achieve satisfactory alignment and favorable outcomes in adult spinal deformity surgery. Stopping the upper instrumented vertebra (UIV) at the thoracolumbar junction levels, especially between T11 and L1, is considered a high-risk factor for the development of proximal junctional kyphosis (PJK). Nevertheless, it is unknown in which patients the results of surgery are satisfactory when L1 or L2 is set as UIV with lumbosacral fixation. This study aimed to identify the risk factors for PJK in patients with lumbosacral fixation with L1 or L2 as UIV.

Methods: From January 2011 to December 2019, 21 consecutive patients who underwent lumbopelvic fixation for adult spinal deformity were included. The patients were divided into two groups: the PJK group (n=7) and the nonPJK group (n=14). Patients who experienced PJK within half a year of surgery were included in the PJK group. Pelvic incidence (PI), lumbar lordosis (LL), pelvic tilt (PT), thoracic kyphosis (TK), thoracic compensation (TK compensation), sagittal vertical axis (SVA), T10-L2 angle, and T1 pelvic angle (TPA) were measured before and after surgery.

Results: No difference was found between the two groups in terms of age and sex at the time of surgery. The indices that were significantly different between the two groups were preoperative PT, PI minus LL, TK, TPA, TK compensation, and postoperative T10-L2 angle. No significant differences were found in postoperative LL, PI minus LL, PT, TK, TPA, or SVA.

Conclusions: Preoperative X-ray indices, including preoperative TPA, TK compensation, TK, PT, and PI-LL, determined the risk of PJK in fusions from the sacrum to L1 or L2. Appropriate patient selection is crucial for the success of this surgery.

Keywords:

adult spinal deformity, thoracolumbar junction, upper instrumented vertebra

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Introduction

Adult spinal deformities (ASDs) include a wide variety of disorders. Surgical management of ASD often requires long fusion constructs. One of the common complications is proximal junctional kyphosis (PJK) and proximal junctional failure (PJF)¹⁾. The incidence of PJK ranges from 5% to 46%; approximately 66% of PJK cases can be identified within 3 months after surgery, with 80% of patients with PJK experiencing PJK recurrence within 18 months of surgery²⁾. PJK can lead to the deterioration of sagittal alignment, vertebral collapse, and neurologic injury, prompting surgeons to develop techniques and strategies against these inferior clinical outcomes thus preventing PJK.

PJK has a multifactorial etiology, with proposed mechanisms that include extensive paraspinal muscle dissection, disruption of the posterior ligamentous tension band, upper instrumented vertebra (UIV) selection, choice of surgical approach, proximal disc degeneration, degrees of correction, compression fracture at or around the UIV, facet violation, pedicle screw instrumentation at UIV, fusion to sacrum/pelvis/ilium, and patient factors such as age, body mass index, osteoporosis, and preoperative malalignment¹⁾.

Stopping UIV at the thoracolumbar junction levels, especially between T11 and L1, is considered a high-risk factor for the development of PJK³⁻⁹⁾. This is due to the change from the less mobile thoracic spine to the highly mobile lumbar spine at the thoracolumbar junction. Thus, a certain

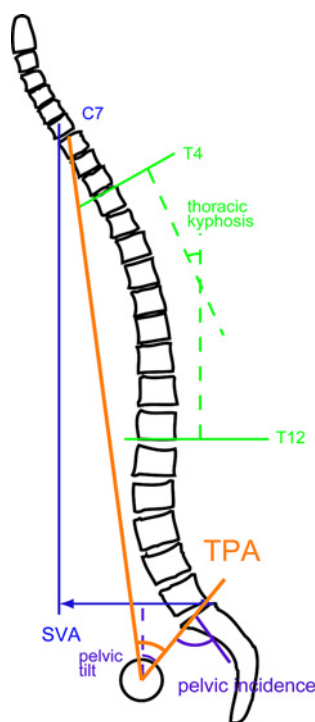


Figure 1. Sagittal radiographic spinopelvic parameters.

LL: lumbar lordosis, PI: pelvic incidence, PT: pelvic tilt, TK: thoracic kyphosis, TPA: T1 pelvic angle, SS: sacral slope, SVA: sagittal vertical axis

number of surgeons choose to extend UIV to the upper thoracic level or at least above T10 to avoid PJK. However, extending the fusion more proximally increases the operation time, blood loss, and the possibility of perioperative complications, pseudoarthrosis, and revision surgery⁹.

The major components of the deformity are often limited to the lumbar spine. It is better if fixation limited to the lumbar spine restores spinal balance and does not increase the risk of PJK. It was noticed that a certain group of patients did not experience PJK, whereas others experienced PJK soon after the surgery when the UIV was set at the upper lumbar vertebrae and sacrum/pelvis/ilium was set as the caudal end. Therefore, this study aimed to investigate the risk factors for PJK after instrumented fusion starting from the sacrum/pelvis/ilium and stopping at L1 and L2.

Materials and Methods

Patients

Between January 2011 and December 2019, 178 patients underwent reconstructive surgery for ASD. Among them, cases with UIV levels at L1 or L2 were selected. To minimize confounders, the distal fusion level was set to the sacrum and/or ilium. The inclusion criteria were patients older

than 50 years, fulfilling the radiographic criteria of ASD (sagittal vertical axis (SVA)>50 mm, coronal Cobb angle > 20°, and pelvic tilt (PT)>25° or thoracic kyphosis (TK)> 60°), with surgery of UIV at L1 or L2 with the sacral fusion of the lowest instrumented vertebrae with/without iliac fixation and with a minimum of 6-month follow-up. The determination of the UIV was based on surgeon preference in assessing both sagittal and coronal plane deformities. Patients with ankylosing spondylitis, diffuse idiopathic systemic hyperostosis, or spinal infection were excluded from the study. All patients underwent pedicle screw instrumentation and fusion without the use of a laminar or transverse process hook at the UIV.

This study was approved by the ethics committee of the authors' affiliated institution.

Outcome parameters

To judge the PJK, the proximal junctional angle (PJA), which is the angle between the inferior endplate of the UIV and the superior endplate of the second vertebral body above the UIV (two levels above) using the sagittal Cobb method, was measured. PJK was defined as PJA $\geq 5^\circ$, and at least 10° greater than the preoperative measurements within 6 months of surgery².

Radiographic measurements

The following parameters were measured on the digitalized radiographs of the whole spine, preoperatively and at 2-12 weeks postoperatively: pelvic incidence (PI), sacral slope (SS), PT, lumbar lordosis (LL, L1-S1), PJA, TK (T4-T12 sagittal Cobb angle), T10-L2 sagittal Cobb angle, L4-S1 sagittal angle, T1 pelvic angle (TPA), and SVA (Fig. 1)¹⁰. The expected TK (eTK) was calculated using the following formula: $eTK = PI - 20^{11}$, on the basis of the idea that ideal TK, LL, and PI fit the formula $LL = 0.5 (PI + TK) + 10$. The amount of thoracic compensation was the difference between the baseline standing TK and eTK¹¹. Positive values of the T10-L2 kyphotic angle and TK indicated kyphotic curvature, whereas positive values of LL and L4-S1 angle indicate lordotic curvature.

Statistical analyses

All statistical analyses were performed with JMP pro15 (SAS Institute Inc., NC, USA) using a two-tailed paired t-test (two conditions). Risk estimation was performed using logistic regression analysis. Statistical significance was set at $p < 0.05$.

Results

The study included a total of 21 patients with a mean age of 69.4 ± 11.0 years, composed of 61.9% female, with 42.9% of patients having had a history of previous lumbar surgery. UIV was L2 in 90.5% of patients, and iliac fixation was performed in 80.9% of patients. Table 1 shows the characteristics of the study subjects.

Table 1. Comparison of Patient and Surgical Risk Factors.

	Total (n=21)	PJK (6 months)		P-value
		Yes (n=7)	No (n=14)	
Age	69.4 (11.0)	67.4 (13.0)	70.3 (10.3)	0.31
Female, n (%)	13 (61.9)	5 (71.4)	8 (57.1)	0.66
BMI	23.8 (3.4)	23.7 (4.2)	23.2 (3.1)	0.4
Smoker, n (%)	8 (38.1)	4 (57.1)	4 (28.6)	0.35
UIV level				1
L1, n (%)	2 (9.5)	1 (14.3)	1 (7.1)	
L2, n (%)	19 (90.5)	6 (85.7)	13 (92.9)	
Iliac fixation, n (%)	17 (80.9)	6 (85.7)	11 (78.6)	1
Previous surgery, n (%)	9 (42.9)	3 (42.9)	6 (42.9)	1
A-P approach, n (%)	14 (66.7)	5 (71.4)	9 (64.3)	1
PSO, n (%)	3 (14.2)	2 (28.6)	1 (7.1)	0.25
Reoperation, n (<2 years, %)	4 (19.0)	4 (57.1)	0 (0)	<0.01

PJK, proximal junctional kyphosis; UIV, upper instrumented vertebrae; PSO, pedicle subtraction osteotomy

Table 2. Comparison of Preoperative Radiographic Indices.

PJK (6 months)	Yes (n=7)	No (n=14)	P-value
LL	3.1 (14.1)	9.3 (13.4)	0.18
PI	56.3 (12.1)	48.9 (11.0)	0.1
PI-LL	53.3 (10.8)	39.6 (18.0)	<0.05
PT	40.3 (10.8)	29.1 (14.4)	<0.05
TK	9.9 (10.9)	19.5 (10.7)	<0.05
T10-L2	-6.4 (19.1)	-2.3 (8.5)	0.3
L4-S1	11.0 (16.2)	9.8 (12.9)	0.39
TPA	47.0 (9.7)	34.6 (15.5)	<0.05
SS	16.1 (16.0)	19.7 (12.3)	0.3
SVA	141.4 (46.9)	116.7 (36.6)	0.13
Expected TK	36.4 (12.1)	28.9 (11.0)	0.1
TK compensation	26.4 (13.6)	9.4 (12.2)	<0.01

LL, lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; TK, thoracic kyphosis; TPA, T1 pelvic angle; SS, sacral slope; SVA, sagittal vertical axis

Table 3. Comparison of Postoperative Radiographic Indices.

PJK (6 months)	Yes (n=6)	No (n=14)	P-value
LL	26.8 (7.6)	24.0 (12.3)	0.26
PI-LL	29.5 (7.1)	24.8 (11.9)	0.14
PT	28.5 (6.6)	36.7 (10.7)	0.33
TK	24.8 (11.2)	26.2 (12.9)	0.4
T10-L2	15.0 (8.0)	3.3 (7.8)	<0.01
L4-S1	24.5 (9.8)	17.4 (8.6)	0.06
TPA	24.1 (5.6)	21.2 (9.1)	0.38
SS	26.5 (9.4)	22.1 (11.7)	0.2
SVA	70.3 (40.7)	53.3 (42.7)	0.21

*: One patient experienced PJK before taking the whole spine X-ray.

Table 4. Comparison of Change in Radiographic Parameters before and after Surgery.

PJK (6 months)	Yes (n=6)	No (n=14)	P-value
LL change	23.8 (13.6)	14.8 (19.9)	0.12
PT change	-24.0 (14.5)	-15.9 (13.4)	0.14
TK change	12.3 (14.3)	6.8 (14.3)	0.22
T10-L2 change	17.8 (14.4)	5.5 (6.3)	<0.05
L4-S1 change	9.8 (14.6)	7.6 (12.2)	0.38
TPA change	-21.9 (10.3)	-13.4 (12.5)	0.07

posterior approach between the groups. Seven patients had PJK; interestingly, 57.1% of patients with PJK underwent revision surgery for ASD within 2 years of index surgery, whereas patients without PJK received no revision surgery within 2 years. The reasons for the revision surgery were the backout of the pedicle screw (n=3) and the proximal junctional fracture with a neurological deficit (n=1). Table 2 shows the preoperative radiographic parameters. There were no statistically significant differences in preoperative LL, PI, T10-L2 angle, L4-S1 angle, SS, and SVA between patients with and without PJK. Patients with PJK had greater PI-LL deformity, PT, TK, TPA, and TK compensation ($p<0.05$, 0.05, 0.05, 0.05, and 0.01, respectively).

Postoperatively, one patient experienced PJK within 2 weeks of index surgery, and a standing whole spine radiograph could not be obtained. Significant improvements were achieved in LL, PI-LL, PT, TK, L4-S1 angle, TPA, SS, and SVA ($p<0.001$, 0.001, 0.05, 0.01, 0.01, 0.001, 0.05, and 0.001, respectively). Postoperative LL, PT, PI-LL, TK, L4-S1 angle, and SS were comparable between patients with and without PJK, whereas SVA was not different. Patients with PJK had a greater T10-L2 kyphotic angle ($p<0.01$, Table 3).

Table 4 shows the changes from preoperative to postoperative alignment. No significant differences were found in the changes in LL, PT, TK, and TPA between the groups.

There were no differences in age, sex, percentage of smokers, UIV level, history of lumbar surgery, and anterior-

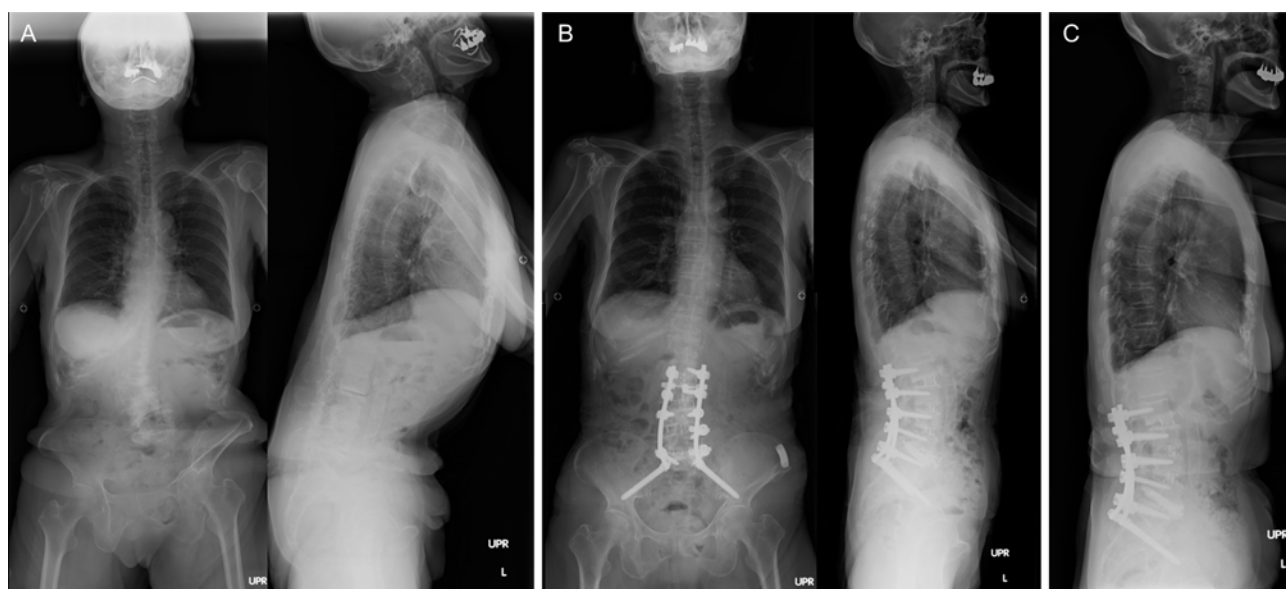


Figure 2. An 85-year-old female without proximal junctional kyphosis treated with an anterior–posterior corrected spinal fusion from L2 to the ilium. A. Preoperative X-ray images. B, C. X-ray images at postoperative 1 month (B) and 2 years (C).

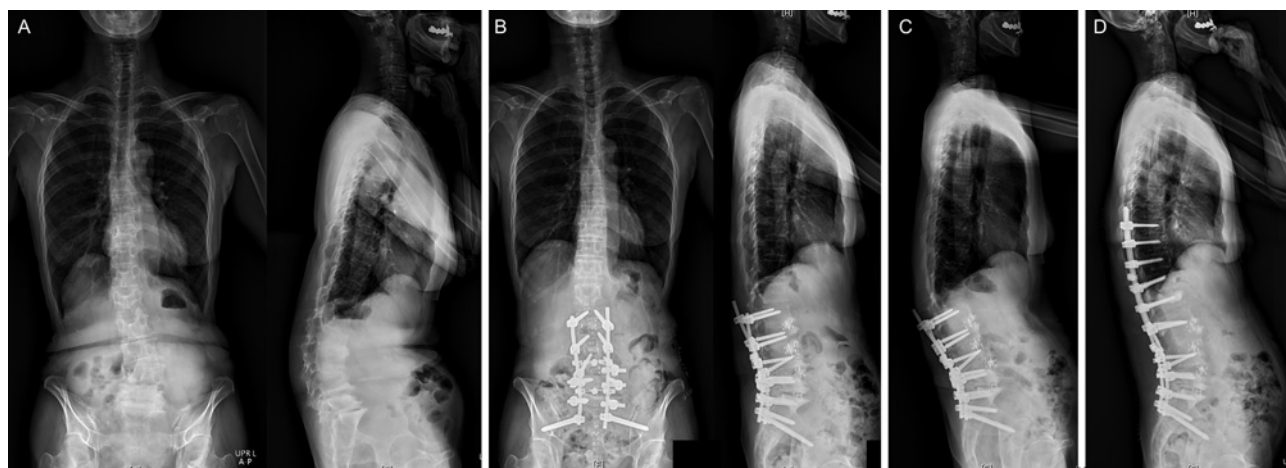


Figure 3. A 60-year-old female with proximal junctional kyphosis treated with anterior–posterior corrected spinal fusion from L2 to ilium with L3–L5 ponte osteotomy. A. Preoperative X-ray images. B, C. X-ray images at postoperative 1 month (B) and 4 months (C). D. X-ray images after the revision surgery.

The T10–L2 angle change was greater in patients with PJK (Table 4).

Using the receiver operating characteristic curve, the cut-off values of perioperative factors, including preoperative PT, PI–LL, TK, TPA, TK compensation, and postoperative T10–L2 angle, were determined to be predictive of the risk of PJK. A univariate logistic regression analysis was then performed. The odds ratio was higher in the following order: TPA>45°, TK compensation >15°, postoperative T10–L2 angle >15°, preoperative TK<10°, preoperative PI–LL>45°, and preoperative PT>30° (Table 5).

We present typical two cases. An 85-year-old female with standing difficulty was treated with anterior–posterior corrected spinal fusion from L2 to the ilium (Fig. 2). Her preoperative PI–LL, TK, PT, SVA, TPA, and TK compensation were 42.8°, 15°, 28°, 140 mm, 38°, and 28°. Her postopera-

tive PI–LL and SVA were 16.2 and 52.5 mm. She did not experience PJK for 2 years after the corrective surgery. Conversely, a 60-year-old female with standing difficulty was treated with anterior–posterior corrected spinal fusion from L2 to ilium with L3–L5 ponte osteotomy (Fig. 3). Her preoperative PI–LL, TK, PT, SVA, TPA, and TK compensation were 53.5°, 1°, 50°, 96 mm, 51°, and 13°. Her postoperative PI–LL and SVA were 15.8° and 53.9 mm. However, she experienced PJF 4 months after the corrective surgery with the backout of the pedicle screws. She required revision surgery to T9 with L3 pedicle subtraction osteotomy.

Discussion

To achieve restoration of coronal and sagittal imbalance and avoid proximal junctional problems, the selection of

Table 5. Odd's Ratio of the Risk Factor of PJK.

	Odd's ratio	P-value
preoperative PI-LL>45	10.8	0.0243
preoperative PT>30	10.8	0.0243
preoperative TK<10	17.3	0.0122
preoperative TPA>45	22	0.0038
preoperative TK compensation>15	22	0.0038
postoperative T10-L2>15	18.3	0.0083

UIV in ASD surgery is necessary. Classically, UIV is determined at neutral and stable vertebrae with healthy adjacent segments without degeneration or instability^{8,12}. At this point, the selection of UIV at the thoracolumbar level was avoided as it increases the likelihood of proximal junctional problems such as PJK or PJF^{4,5,7,8}. Some reports recommended extension to T9 or above for longer survival of adjacent levels^{7,13}.

However, several studies suggested that the risk of PJK or PJF did not increase even with the UIV at the thoracolumbar junction levels when compared with UIV above the thoracolumbar junction level^{5,8,14,15}. Most studies have analyzed cases with various ASD surgeries and concluded that PJK or PJF frequently occurred when UIV was set at the thoracolumbar junction level. These studies did not elucidate whether PJF or PJK was avoidable if an appropriate selection of the patients and an appropriate correction of the spinal deformity were performed.

In the present study, we included patients with UIV levels at L1 or L2 and analyzed the risk factors for PJK. We recently reported that three to five degrees of lordosis can be obtained for each interbody fusion of the lumbar spine¹⁶. We targeted postoperative PI-LL of <10° according to the formula, referencing standing and fulcrum bending X-ray. When this goal could not be achieved only by interbody fusion, pedicle subtraction osteotomy was performed mainly at the L4 level to obtain lordosis in the lower lumbar spine. The UIV level at L1 or L2 was selected if the adjacent segments, including the facet joint and disc, were healthy and alignment was neutral. Although we usually choose T10 or above level as UIV for ASD surgery considering the risk of PJK or PJF, L1 or L2 were considered as UIV to leave the mobile segment when the above conditions were met.

According to the Scoliosis Research Society-Schwab classification, the target for achieving satisfactory alignment and favorable outcomes are PI-LL≤10°, PT<20°, and SVA<4 cm^{17,18}. Schwab modifier cutoffs were determined in relation to health-related quality-of-life measures rather than mechanical complications; however, it is not clear how achieving some or all of these criteria influences the risk of mechanical complications. Some authors have suggested other formulas for calculating the ideal PI-LL^{19,20}. The mean values of postoperative PI-LL and PT were 24.7° and 27.6°, respectively, which do not satisfy the above criteria; nevertheless, there were no differences in postoperative PI-LL and

PT between the patients with and without PJK. Interestingly, there were cases in which PJK occurred soon after surgery or did not occur although the same correction angle was obtained in the two groups.

Park et al. recently reported the risk factors for PJF following a long fusion for ASD, stopping at the thoracolumbar junction⁸. They did not find any risk factors from postoperative radiographic parameters or changes in parameters. Instead, they reported age of >70 years, osteoporosis, preoperative PT, PI-LL, and PJA as risk factors for PJF. In their study, UIVs were T11, T12, and L1, and the occurrence of PJF was investigated for an indefinite period of time. Interestingly, similar preoperative risk factors were found, although the target patients were different.

Moridaira et al. also attempted to identify the factors that would make ASD surgery successful with short fusion. They concluded that the use of short fusion can produce adequate LL for PI and improve Oswestry Disability Index if the PI is <47° in patients whose deformity is mainly limited to lumbar kyphosis²⁰.

Compensation mechanisms for age-related imbalance include pelvic retroversion following LL. Hypokyphosis of the thoracic spine is a well-described compensatory mechanism for decreased LL and lumbopelvic mismatch²¹. Increased TK can be seen as a failure of the thoracic compensatory mechanisms. Schwab et al. proposed ideal TK and LL values on the basis of the patient's PI and provided the eTK and thoracic compensation¹¹. Considering these parameters, it can be said that patients with PJK have greater TK compensation and are more likely to have advanced deformities than those without PJK (Table 2). TPA, which corresponds to the angle between a line connecting the center of T1 to the center of the femoral head and the line to the center of the S1 endplate, is correlated with PT and SVA^{10,22}. A higher TPA will also support the idea that patients with PJK are at a more advanced stage of deformity.

Recently, X-rays in the sitting position were shown to be useful to predict the risk of PJK²³. LL decreases by approximately 50% and PT increases by approximately 25% in the sitting position compared with the standing position²⁴. Because ASD patients spend most of their daily living in the relaxed natural sitting position, it is reasonable to think that the radiographic parameter in the sitting position or differences of parameters between the sitting and standing position would affect the PJK. Interestingly, Yoshida et al. demonstrated the distance between the C2 plumb line and UIV in the sitting position was the most predictive factor for PJK²³. Although X-rays were not taken in the sitting position in this study, it is possible that UIV levels can be stopped at L1 or L2 level in patients with smaller C2 to UIV distance.

We could not find risk factors from postoperative radiographic parameters except for the T10-L2 angle, which means that the surgery was performed with a certain alignment. Except for treatment in which L1 or L2 is limited to UIV, there are reports of negative reciprocal changes in the

thoracic spine after surgery in patients with ASD²⁵⁾. Reportedly, this postoperative reciprocal change causes PJK^{11,26)}, and preoperative TK compensation, preoperative TK, and age have been reported as risk factors for reciprocal change^{11,27)}. These reports are consistent with our results that lower preoperative TK and higher TK compensation are associated with PJK, whereas a higher postoperative T10-L2 angle is a risk factor for PJK.

This study had several limitations. First, this study is retrospective in nature; a high risk of PJK for ASD patients can be anticipated for the surgery in which UIV is set at L1 or L2 with sacral fixation. Hence, the indications for this surgery were carefully considered, and there may be a bias in patient selection, which may prevent the generalization of the results. Second, as a primary outcome, we investigated the risk factors for PJK within 6 months after surgery. Because of the small number of cases, we could not investigate the risk factors for PJF with a longer follow-up period. Third, we could not determine the risk factors for PJK by performing multivariate analysis because of the small number of cases.

The strength of this study is the narrow inclusion criteria, which includes UIV at L1 or L2, and fusion to the sacrum. Studies so far have reported that selecting the thoracolumbar junction as a UIV increases the likelihood of proximal junctional problems, and there is no report on what kind of cases in which L1 and L2 can be selected as UIV. In this sense, this study is valuable.

Conclusions

Preoperative X-ray indices including TPA, TK compensation, TK, PT, PI-LL, and postoperative T10-L2 angle determined the risk of PJK in fusions from the sacrum to L1 or L2 for ASD. Appropriate patient selection is crucial for the success of this surgery.

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

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Author Contributions: KM and SF conceived and designed the study. Analyzed the data: KM. Collection of data and read radiographs: KM, SF, BO, and TS. Wrote the paper: KM. Supervision of the manuscript: SF and SM. All authors read and approved the final manuscript.

Ethical Approval: This study was approved by the Ethics Committee of Kyoto University Graduate School and Faculty of Medicine (E2067). The board waived the requirement for patients' informed consent because of its retrospective design.

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