Original Article
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Radiographic Factors of Proximal Junctional Failure According to Age Groups in Adult Spinal Deformity

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Background: Patient age has been associated with the development of proximal junctional failure (PJF). The characteristics of adult spinal deformity (ASD) are considered different between younger and older age groups. We hypothesized that the radiographic risk factors of PJF would be different according to age groups. This study aimed to evaluate different radiographic risk factors of PJF between two age groups undergoing thoracolumbar fusion for ASD.

Methods: ASD patients aged ≥ 60 years who underwent thoracolumbar fusion from the low thoracic level (T9–T12) to the sacrum were included. The minimum follow-up duration was 2 years. PJF was defined as proximal junctional angle (PJA) ≥ 20°, fixation failure, fracture, myelopathy, or necessity of revision surgery. Using various radiographic risk factors including age-adjusted ideal pelvic incidence (PI)-lumbar lordosis (LL), univariate and multivariate analyses were performed separately in two age groups: < 70 years and ≥ 70 years.

Results: A total of 186 patients (90.3% women) with a mean age of 69 years were enrolled. The mean follow-up duration was 67.4 months. PJF developed in 97 patients (52.2%). There were fractures in 53 patients, PJA ≥ 20° in 26, fixation failure in 12, and myelopathy in 6. PJF developed more frequently in patients 70 years or older than in those younger than 70 years. In patients aged less than 70 years, preoperative LL, PI-LL, and a change in LL were significant risk factors in univariate analysis. Multivariate analysis showed only a change in LL was significant for PJF development (odds ratio [OR], 1.025; $p = 0.021$). On the other hand, in patients 70 years or older, postoperative LL, postoperative PI-LL, and overcorrection relative to the conventional PI-LL target (within ± 10°) and age-adjusted ideal PI-LL target were significant risk factors. On multivariate analysis, only overcorrection of PI-LL relative to the age-adjusted ideal target was a single significant risk factor of PJF (OR, 5.250; $p = 0.024$).

Conclusions: In patients younger than 70 years, a greater change in LL was associated with PJF development regardless of PI-related values. However, in older patients, overcorrection of PI-LL relative to the age-adjusted PI-LL target was a significant risk factor of PJF.

Keywords: *Adult spinal deformity, Age-adjusted alignment goal, Lumbar lordosis, Pelvic incidence-lumbar lordosis, Proximal junctional failure*

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Proximal junctional failure (PJF) is one of the most common mechanical complications that can potentially worsen the clinical outcomes and sometimes requires revision surgery in adult spinal deformity (ASD).[1-3] To date, a number of risk factors have been widely suggested including older age, obesity, osteoporosis, anteroposterior surgery, the inclusion of the sacrum, stopping at a lower thoracic level, preoperative severe sagittal imbalance, and the overcorrection of sagittal alignment.[1,4-13]

Among these risk factors, radiographic variables have been one of the most important risk factors for PJF.[11] The radiographic risk factors reported in the literature are as follows: a great correction of sagittal vertical axis (SVA),[1,4,7,9,14] postoperative large lumbar lordosis (LL),[6,7] a greater change in LL,[6] and a postoperative small pelvic incidence (PI)-LL mismatch.[15,16] More recently, the concept of age-adjusted sagittal alignment has gathered attention, since it was reported that the values of sagittal parameters in asymptomatic patients vary with age.[10,17,18] Lafage et al.[18] suggested that the sagittal spinopelvic parameters should be evaluated with consideration of the patient's age.

Patient age has been considered a strong risk factor for PJF development.[1,7,8,19,20] Even among the ASD patients, various characteristics of the patient, such as frailty, bone quality, muscle and ligament tension, and adaptive capacity to reconstructed spine, are inevitably different depending on age. Therefore, the assessment of PJF in ASD patients needs to be stratified according to patient age. We hypothesized that the radiographic risk factors for PJF would differ according to age. Therefore, in the present study, the risk factors for PJF were examined separately in two age groups among patients undergoing thoracolumbar fusion for ASD.

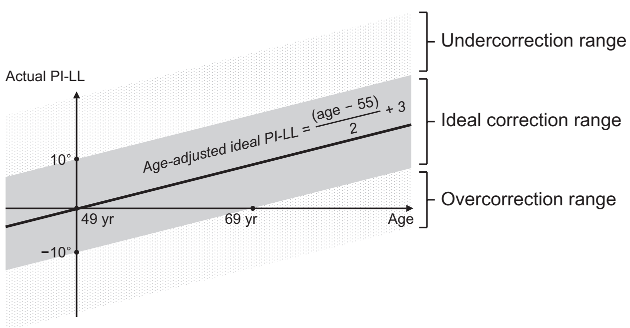

Fig. 1. A graph showing the ranges of undercorrection, ideal correction, and overcorrection of the age-adjusted ideal pelvic incidence-lumbar lordosis (PI-LL) mismatch according to patient age. The age of 69 years was the age at which the ideal PI-LL (formula: [age – 55] / 2 + 3) was equal to 10°.

METHODS

Study Cohort and Operative Methods

This study was approved by the Institutional Review Board of our institution (No. 2022-07-013). This study was a retrospective case series, which included records retrieved from our tertiary hospital's ASD database. Eligible individuals for the present study included patients older than 60 years with sagittal imbalance who had undergone thoracolumbar fusion including the sacrum between 2014 and 2020. Patients with a total fusion length of 6 to 9 levels (T12-S1 to T9-S1) were included. All surgeries were performed by coauthors. Chief complaints were stooping and low back pain. The study cohort consisted of patients who met one or more of the following radiographic criteria: (1) SVA greater than 50 mm, (2) PI-LL greater than 10°, (3) pelvic tilt (PT) greater than 25°, and (4) a coronal Cobb angle at least 20°. The minimum follow-up period was 2 years. Patients with prior fusion surgery were included if the previous fusion length was less than 2 levels.

Two different age groups were created by considering the age-adjusted ideal PI-LL formula ([age –55] / 2 + 3) and the conventional optimum PI-LL range. The age of 69 years was calculated when the age-considered ideal PI-LL was equal to 10°, which is the upper margin of the ideal conventional PI-LL target (Fig. 1). Therefore, two age groups were created as follows: age < 70 and ≥ 70 years.

Corrective surgery was performed using a posterior approach only or a combination of the anterior and posterior approaches, depending on the patient's preoperative deformity. However, the preferred surgical technique at our institution was the combined anterior and posterior approaches. All surgeries were performed using the open method with 5.5-mm titanium rods. Iliac screw fixation was routinely performed except for patients with previous L5–S1 fusion operations.

Definition of PJF

According to the conventional definition by Hostin et al.[21] and Hart et al.,[22] PJF was defined as posterior ligament disruption, vertebral fracture at the uppermost instrumented vertebra (UIV) or UIV + 1, the pullout of UIV fixation, myelopathy, or the need for revision surgery. The proximal junctional angle (PJA) criterion was set as ≥ 20° for diagnosing the posterior ligament disruption. According to the presence or absence of PJF, two groups were created as the PJF and non-PJF groups.

Radiographic Risk Factors

Conventional sagittal parameters such as PI, LL, sacral slope (SS), PT, and SVA were measured on whole-spine 36-inch standing radiographs taken preoperatively and 4 weeks postoperatively.[23)] PJF was assessed using plain radiographs obtained at routine follow-up sessions at 3 and 6 months postoperatively and then annually thereafter. If PJF had developed before 4 weeks postoperatively, we adopted earlier radiographs obtained before PJF development. To identify the relevant radiographic parameters causing PJF, preoperative and 4-week postoperative sagittal parameters and their changes were compared between the PJF and non-PJF groups. In addition, to assess the effect of sagittal alignment suggested by the SRS-Schwab classification on the development of PJF, postoperative PI-LL was classified into three groups as follows: > 10°, within ± 10°, and ≤ –10°.[24,25)] Finally, the effect of age-adjusted alignment target on PJF development was analyzed. The age-adjusted ideal PI-LL was calculated using a previously reported formula: PI-LL = (age – 55) / 2 + 3.18,[26)] Next, the offset value between the actual PI-LL and the age-adjusted ideal PI-LL was determined using the following formula: (age-adjusted ideal PI-LL) – (actual postoperative PI-LL).[10)] Then, the patients were divided into three groups according to the offset value as follows: undercorrection (offset < –10°), ideal correction (offset within ± 10°), and overcorrection (offset > 10°).

Table 1. Demographic and Operative Data

Characteristics	Value (N = 186)
Demographic data	
Age (yr)	69 ± 7
Age < 70 yr	100 (53.8)
Female	168 (90.3)
ASA grade	2.1 ± 0.5
BMI (kg/m^2)	25.6 ± 3.1
Osteoporosis	47 (25.2)
Operative data	
Total fusion level	7.6 ± 2.3
UIV	
T9	15 (8.1)
T10	106 (60.0)
T11	38 (20.4)
T12	27 (14.5)
Previous fusion surgery (≤ 2 levels)	40 (21.5)
Front-back surgery	111 (59.7)
PSO	36 (19.4)
Iliac fixation	119 (64.0)

Values are presented as mean ± standard deviation or number (%).
ASA: American Society of Anesthesiologists, BMI: body mass index, UIV: uppermost instrumented vertebra, PSO: pedicle subtraction osteotomy.

Statistical Analysis

The data are presented as frequencies with percentages for categorical variables and as means with standard deviations for continuous variables. A univariate analysis was performed using Fisher's exact tests to compare the categorical variables and Student *t*-tests to assess differences in the means of the continuous variables between the two groups. Multivariate logistic regression analysis was performed with the forward logistic regression method using all variables that had a significance of < 0.05 in the univariate analysis. Univariate and multivariate analyses were performed separately in the two age groups, which were < 70 years and ≥ 70 years. Statistical analyses were carried out by professional statisticians using IBM SPSS ver. 27.0 (IBM Corp., Armonk, NY, USA). A *p*-value of < 0.05 was considered statistically significant.

RESULTS

Demographic and Operative Data

Initially, the present study enrolled 235 patients who met the inclusion criteria. Among the enrolled patients, 36 patients who had previously undergone more than three levels of fusion and 13 patients whose follow-up period was less than 2 years were excluded. A total of 186 patients were enrolled in this study (Table 1). The mean age was 69

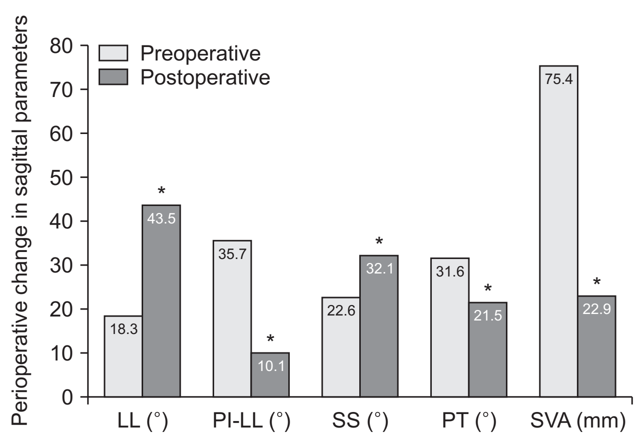

Fig. 2. Perioperative changes in sagittal parameters. LL: lumbar lordosis, PI: pelvic incidence, SS: sacral slope, PT: pelvic tilt, SVA: sagittal vertical axis. *Statistical significance.

years. One hundred patients (53.8%) were under 70 years old. There were 168 women (90.3%). There were 47 patients with osteoporosis. The total fusion level was 7.6 segments with UIV of T9 in 15 patients, T10 in 106, T11 in 38, and T12 in 27. More than half of the patients received front-back surgery (59.7%). Pedicle subtraction osteotomy was performed in 36 patients (19.4%). After surgery, all sagittal parameters including LL, PI-LL, SS, PT, and SVA significantly improved (Fig. 2). LL improved from 18.3° preoperatively to 43.5° postoperatively. PI-LL was reduced from 35.7° preoperatively to 10.1° postoperatively.

PJF Data

The follow-up duration was a mean of 67.4 months. During follow-up, PJF developed in 97 patients (52.2%) at a mean postoperative period of 13.1 months. PJF developed significantly more frequently in patients 70 years or older (65.1%, 56/86 patients) than in younger than 70 years (41%, 41/100 patients) (p = 0001). Of the PJF cases, 73 patients (75.3%) developed PJF within 1 year after surgery. On the mode of PJF, fracture at UIV or UIV + 1 was most common (53 patients, 54.6%), followed by PJA ≥ 20° (26 patients, 26.8%), the pullout of UIV fixation (12 patients, 12.4%), and myelopathy (6 patients, 6.2%). Revision sur-

Table 2. Univariate Analysis of Radiographic Parameters Causing PJF (Age < 70 yr)

Variable	PJF (n = 41)	Non-PJF (n = 59)	*p*-value
Preoperative PI (°)	53.4 ± 11.6	54.4 ± 12.2	0.690
Preoperative LL (°)	13.7 ± 20.5	23.0 ± 21.5	0.032*
Preoperative PI-LL (°)	39.7 ± 19.0	31.4 ± 20.7	0.043*
Preoperative SS (°)	20.9 ± 12.1	25.5 ± 11.0	0.053
Preoperative PT (°)	32.4 ± 11.4	28.9 ± 10.9	0.116
Preoperative SVA (mm)	76.4 ± 55.7	64.6 ± 50.6	0.273
Postoperative LL (°)	43.4 ± 13.2	43.0 ± 12.3	0.880
Postoperative PI-LL (°)	9.8 ± 13.8	10.8 ± 12.6	0.727
Grouping by conventional optimal PI-LL			0.326
PI-LL >10°	17 (41.5)	29 (49.2)	
–10° ≤ PI-LL ≤ 10°	21 (51.2)	29 (49.2)	
PI-LL < –10°	3 (7.3)	1 (1.7)	
Grouping by age-adjusted ideal PI-LL target†			0.757
Undercorrection	12 (29.3)	15 (25.4)	
Ideal correction	22 (53.7)	36 (61.0)	
Overcorrection	7 (17.1)	8 (13.6)	
Postoperative SS (°)	30.7 ± 7.8	22.4 ± 10.3	0.283
Postoperative PT (°)	22.4 ± 10.3	20.8 ± 9.5	0.411
Postoperative SVA (mm)	18.5 ± 32.9	20.4 ± 25.1	0.742
Change in LL (°)	29.7 ± 22.9	19.9 ± 16.9	0.017*
Change in PT (°)	10.0 ± 11.1	8.1 ± 7.9	0.312
Change in SVA (mm)	57.9 ± 53.8	44.2 ± 49.7	0.192

Values are presented as mean ± standard deviation or number (%).
PJF: proximal junctional failure, PI: pelvic incidence, LL: lumbar lordosis, SS: sacral slope, PT: pelvic tilt, SVA: sagittal vertical axis.
**p*-values indicate statistical significance. †Age-adjusted ideal PI-LL target was calculated as follows: age-adjusted ideal PI-LL = (age – 55) / 2 + 3. Offset was calculated using the following formula: (age-adjusted ideal PI-LL) – (actual postoperative PI-LL). According to offset, undercorrrection means offset < –10°, ideal correction means offset within ± 10°, and overcorrection means offset > 10°.

gery was required in 23 of 97 patients with PJF (23.7%).

Risk Factor Analysis in Patients under 70 Years

Univariate analysis for patients under 70 years old (Table 2) showed significant differences between the PJF and non-PJF groups in terms of preoperative LL (13.7° vs. 23.0°, p = 0.032), preoperative PI-LL (39.7° vs. 31.4°, p = 0.043), and change in LL (29.7° vs. 19.9°, p = 0.017). There were no differences between two groups with regard to grouping by the conventional PI-LL target or age-considered ideal PI-LL target. Multivariate analysis revealed that the change in LL was a single significant factor associated with PJF (odds ratio [OR], 1.025; 95% confidence interval [CI], 1.004–1.047; p = 0.021) (Table 3). The cutoff value of LL change for PJF development was calculated as 23° under the receiver operating characteristic (ROC) curve (area under the curve, 0.624; 95% CI, 0.510–0.739; p = 0.035) (Fig. 3).

Risk Factor Analysis in Patients 70 Years or Older

In the univariate analysis of patients aged 70 years or older, there were significant differences between the PJF and non-PJF groups with regard to postoperative LL (46.6° vs. 39.3°, p = 0.002), postoperative PI-LL (6.4° vs. 15.6°, p = 0.001), categories grouped by the conventional optimal PI-LL range (p = 0.020), and categories grouped by the age-adjusted ideal PI-LL target (p = 0.001) (Table 4). In the multivariate analysis, only correction amount according to the age-adjusted ideal PI-LL target was a significant risk factor for PJF development (Table 3). Overcorrection relative to the age-considered PI-LL target significantly increased the risk of PJF than the ideal correction and undercorrection did.

Characteristics According to Age

The patient characteristics differed significantly between the age groups of < 70 years and ≥ 70 years (Table 5). The mean age was 63.7 years and 71.9 years. The ASA grade was significantly lower in patients ≥ 70 years than in patients < 70 years. There were more patients with osteoporosis in patients ≥ 70 years than in patients < 70 years. The bone mineral densities of the two age groups were –1.25 ± 1.68 and –1.69 ± 1.49. The offset value between the actual and age-adjusted ideal PI-LL was 7.3° in patients < 70

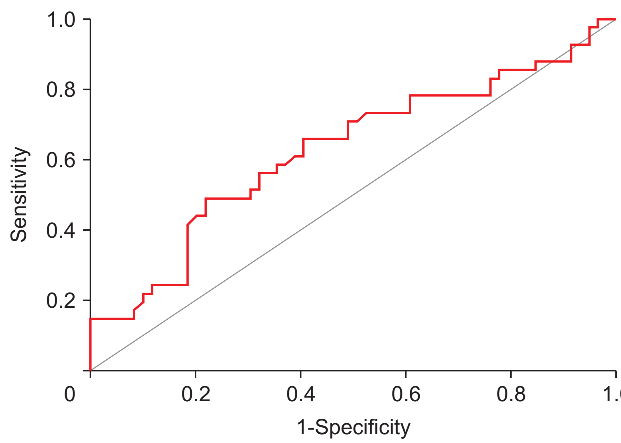

Fig. 3. Receiver operating characteristic curve showing probability of proximal junctional failure according to the lumbar lordosis change (area under the curve, 0.624; 95% confidence interval, 0.510–0.739; p = 0.035).

Table 3. Multivariate Logistic Regression Analysis of the Most Relevant Risk Factors for PJF According to Age Group

Variable	B	SE	Wald	p-value	Exp (B) (95% CI)
Age < 70 yr (n = 100)					
Change in LL	0.025	0.011	5.350	0.021*	1.025 (1.004–1.047)
Constant	–0.977	0.340	8.247	0.004*	0.376
Age ≥ 70 yr (n = 86)					
Categories by age-adjusted ideal PI-LL target†			10.754	0.005*	
Overcorrection (vs. ideal correction)	1.658	0.737	5.067	0.024*	5.250 (1.239–22.243)
Overcorrection (vs. undercorrection)	2.708	0.827	10.715	0.001*	15.000 (2.964–75.910)
Constant	–1.099	0.667	2.716	0.099	0.333

Multivariate analysis was performed with forward LR method using variables that had a significance of < 0.05 in the univariate analysis.
PJF: proximal junctional failure, SE: standard error, CI: confidence interval, PI: pelvic incidence, LL: lumbar lordosis.
*p-values indicate statistical significance. †Undercorrection means offset value between the actual and age-adjusted ideal PI-LL < –10°, ideal correction means offset value within ± 10°, and overcorrection means offset value > 10°.

Table 4. Univariate Analysis of Radiographic Parameters Causing PJF (Age ≥ 70 yr)

Variable	PJF (n = 56)	Non-PJF (n = 30)	*p*-value
Preoperative PI (°)	54.2 ± 10.1	54.8 ± 9.8	0.787
Preoperative LL (°)	17.8 ± 18.6	16.2 ± 15.9	0.685
Preoperative PI-LL (°)	36.3 ± 19.7	38.6 ± 14.5	0.585
Preoperative SS (°)	21.8 ± 10.8	20.4 ± 9.4	0.546
Preoperative PT (°)	32.4 ± 11.4	34.4 ± 6.9	0.377
Preoperative SVA (mm)	86.5 ± 61.9	74.5 ± 51.5	0.370
Postoperative LL (°)	46.6 ± 10.5	39.3 ± 8.8	0.002*
Postoperative PI-LL (°)	6.4 ± 11.3	15.6 ± 10.9	0.001*
Grouping by conventional optimal PI-LL			0.020*
PI-LL >10°	21 (37.5)	20 (66.7)	
−10° ≤ PI-LL ≤ 10°	33 (58.9)	10 (33.3)	
PI-LL < −10°	0	2 (3.6)	
Grouping by age-adjusted ideal PI-LL target[†]			0.001*
Undercorrection	3 (5.4)	9 (30.0)	
Ideal correction	28 (50.0)	16 (53.3)	
Overcorrection	25 (44.6)	5 (16.7)	
Postoperative SS (°)	33.4 ± 7.8	30.5 ± 8.1	0.109
Postoperative PT (°)	20.0 ± 9.5	24.2 ± 9.3	0.055
Postoperative SVA (mm)	26.6 ± 37.2	26.7 ± 31.6	0.989
Change in LL (°)	28.8 ± 18.5	23.1 ± 13.8	0.142
Change in PT (°)	12.3 ± 10.6	10.2 ± 7.1	0.326
Change in SVA (mm)	59.9 ± 58.7	47.8 ± 46.7	0.334

Values are presented as mean ± standard deviation or number (%).
PJF: proximal junctional failure, PI: pelvic incidence, LL: lumbar lordosis, SS: sacral slope, PT: pelvic tilt, SVA: sagittal vertical axis.
**p*-values indicate statistical significance. [†]Age-adjusted ideal PI-LL target was calculated as follows: age-adjusted ideal PI-LL = (age – 55) / 2 + 3. Offset was calculated using the following formula: (age-adjusted ideal PI-LL) – (actual postoperative PI-LL). According to offset, undercorrrection means offset < –10°, ideal correction means offset within ± 10°, and overcorrection means offset > 10°.

years, which was significantly lower than 12.6° in patients ≥ 70 years. The patient distribution according to correction relative to the age-adjusted ideal PI-LL differed between the two age groups: there were significantly greater patients with overcorrection in the ≥ 70 year group than in the < 70 year group.

DISCUSSION

Two different age groups were created by considering the age-adjusted ideal PI-LL formula and range of the conventional optimum PI-LL. The age of 69 years was calculated when the age-considered ideal PI-LL was equal to 10°, which is the upper margin of the ideal conventional PI-LL target (Fig. 1). As the age-adjusted ideal PI-LL can be calculated using the formula ([age – 55] / 2 + 3), the offset between the actual and age-adjusted ideal PI-LL is determined by both the age of the patient and the actual PI-LL. If the PI-LL is corrected to 0° after surgery, it could be overcorrected in association with the age-considered ideal PI-LL in patients aged ≥ 70 years. However, for patients aged < 70 years, a PI-LL of 0° is the ideal correction range. Therefore, the age-adjusted ideal PI-LL concept needs to be applied separately to different age groups. In this study,

Table 5. Patient Characteristics According to Age Group

Characteristics	Age < 70 yr (n = 100)	Age ≥ 70 yr (n = 86)	*p*-value
Age (yr)	63.7 ± 3.7	71.9 ± 6.1	<0.001*
Female	72 (92.3)	96 (88.9)	0.616
ASA grade	1.9 ± 0.4	2.2 ± 0.5	0.001*
BMI (kg/m^2)	25.3 ± 3.1	26.0 ± 3.1	0.187
Osteoporosis	20 (20.0)	30 (34.9)	0.040*
Preoperative PI (°)	54.0 ± 54.1	54.4 ± 10.2	0.815
Preoperative LL (°)	19.2 ± 20.4	17.3 ± 19.2	0.505
Preoperative PI-LL (°)	34.8 ± 20.5	37.1 ± 18.3	0.414
Preoperative SS (°)	23.7 ± 11.1	21.3 ± 10.9	0.148
Preoperative PT (°)	30.3 ± 11.3	33.1 ± 10.3	0.085
Preoperative SVA (mm)	69.4 ± 50.7	82.3 ± 58.5	0.115
Postoperative LL (°)	43.1 ± 12.8	44.0 ± 10.8	0.592
Postoperative PI-LL (°)	10.4 ± 13.4	9.7 ± 11.8	0.711
Age-adjusted ideal PI-LL (°)	7.3 ± 2.0	12.6 ± 1.9	<0.001*
Correction relative to conventional PI-LL target			0.803
PI-LL >10°	46 (46.0)	41 (47.7)	
–10° ≤ PI-LL ≤ 10°	50 (50.0)	43 (50.0)	
PI-LL < –10°	4 (4.0)	2 (2.3)	
Correction relative to age-adjusted ideal PI-LL			0.003
Undercorrection	27 (27.0)	12 (14.0)	
Ideal correction	58 (58.0)	44 (51.25)	
Overcorrection	15 (15.0)	30 (34.9)	
Postoperative SS (°)	31.9 ± 9.3	32.3 ± 8.2	0.749
Postoperative PT (°)	21.4 ± 9.7	21.5 ± 9.7	0.980
Postoperative SVA (mm)	19.6 ± 27.8	26.7 ± 34.2	0.131
Change in LL (°)	23.9 ± 19.7	26.8 ± 18.0	0.302
Change in PT (°)	8.9 ± 8.9	11.6 ± 9.7	0.054
Change in SVA (mm)	49.8 ± 51.5	55.7 ± 54.2	0.455

Values are presented as mean ± standard deviation or number (%).
ASA: American Society of Anesthesiologists, BMI: body mass index, PI: pelvic incidence, LL: lumbar lordosis, SS: sacral slope, PT: pelvic tilt, SVA: sagittal vertical axis.
**p*-values indicate statistical significance.

we divided the patients into two groups: those aged 70 < and those aged ≥ 70 years.

In the present study, we found that the radiographic risk factors for PJF differed between the age groups. In the group of patients < 70 years, the preoperative LL and the preoperative PI-LL, which represent the severity of the preoperative sagittal imbalance, were significantly different between the PJF and non-PJF groups. This finding is consistent with previous studies reporting that severe sagittal imbalance is a risk factor for PJF development.[9,19,27] As in previous studies,[6,7] the amount of LL change was also an important factor associated with the increased risk of PJF in this age group. The multivariate analysis showed that the amount of LL change is a single independent risk factor for PJF. The cutoff value of LL change was calculated as 23° in the ROC analysis.

In the studied age groups, PI and PI-related factors, such as the conventional or age-adjusted PI-LL, did not influence PJF development. This can be explained by several points. First, we should consider patient distribution according to the correction amount relative to the age-adjusted ideal PI-LL. The mean age-adjusted ideal PI-LL was 7.3°, which was set significantly lower than 12.6° in the age ≥ 70 years group (Table 5). A lower ideal PI-LL target conversely indicates less probability of overcorrection. This study showed that 85% in the age < 70 years group belonged to undercorrection or ideal correction and there were only 15% of patients with overcorrection. Regarding the age-adjusted PI-LL target, we can expect that younger patients will have a smaller PI-LL target, which automatically gives a possibility of undercorrection in the setting of conventional PI-LL target. Second, younger patients would have a greater buffer against overcorrection than older patients considering older age itself increases the risk of PJF.[7,8,19] Our study showed that patients < 70 years had a significantly lower ASA score and had less osteoporosis (Table 5). They probably have better soft tissue and bone quality, which could overcome the negative force for PJF development caused by overcorrection.

In the group of age ≥ 70 years, the postoperative LL, PI-LL-related values, and overcorrection relative to conventional optimal PI-LL and age-considered PI-LL values were significant in the univariate analysis. These results indicate various types of overcorrection and are consistent with previous studies.[7,10,16] In a multivariate analysis, the correction relative to the age-adjusted PI-LL target was a single independent risk factor for PJF. As shown in Fig. 1, the age-adjusted PI-LL target increases with age. Therefore, the patients are likely to be overcorrected relative to the age-adjusted ideal target although PI-LL is corrected to the upper limit (10°) of the conventional PI-LL target. This study showed that the number of patients with overcorrection in this age group was significantly greater than that in the < 70 years group (Table 5). Therefore, more strict application to the age-adjusted PI-LL target should be considered in older age groups.

To date, there have been many studies on the etiology and mechanism of PJF. Traditionally, overcorrection of sagittal alignment has been considered a strong radiographic risk factor for PJF development. Overcorrection was differently defined in the literature, such as greater correction of the SVA,[1,4,7,9] greater postoperative LL or its change,[6,7] and postoperative small PI-LL mismatch.[15,16] Although these criteria appear different, all these values are associated with a large LL correction after surgery. Unlike the positional parameters such as SVA or PT, LL is the one that surgeons can control during surgery. Therefore, LL correction is of utmost importance during deformity surgery. A postoperative PI-LL mismatch within ± 9° has been widely used as the surgical goal.[25,28] However, its role in preventing mechanical complications (including PJF) remains controversial. Park et al.[8,19] showed that there were no differences in patients who achieved optimal correction according to the Schwab-SRS classification between PJF and non-PJF groups. Im et al.[15] reported that the degree of LL correction relative to PI did not act as a risk factor for PJK. In the current study, we also found that the conventional PI-LL grouping was not related with PJF development in both age groups. Meanwhile, age-adjusted sagittal alignment has attracted the attention of clinicians who evaluate patients with ASD. Lafage et al.[18] suggested that the sagittal spinopelvic parameters should be evaluated according to age. They argued that younger patients require a more stringent alignment target, whereas less strict rules for sagittal alignment (i.e., PI-LL > 10°) are acceptable for older patients. They also showed that overcorrection of a PI-LL mismatch associated with the age-adjusted alignment target increased PJF risk.[10] Therefore, age should be considered in the surgical planning of ASD treatment.

A few limitations of this study should be acknowledged. First, the operative techniques and fusion length were not standardized. However, each surgeon tried to follow the current basic principles regarding correction amount and UIV selection. Second, our definition of PJF did not cover all types of PJF. In this study, we excluded patients with mild forms of PJF; the cutoff values for PJA for the diagnosis of PJF were reported to be 10° and 15°.[5,21,29] We adopted 20° as the diagnostic criterion for posterior ligament disruption because a PJA of > 20° has been associated with poor clinical results.[5] Although many PJF studies have included patients with all types of PJF, the authors believe that it would be better if patients with mild asymptomatic PJF were excluded for better clinical relevance. Third, there could be other confounding factors other than the suggested radiographic risk factors, such as osteoporosis associated with PJF; however, the present study overcome this limitation with a relatively large patient cohort (186 patients). Additionally, rod fractures should be considered as a confounding factor; moreover, in this study, we found 59 patients with rod fractures. However, as the present study focused on the radiographic risk factors of PJF according to age groups, future studies are needed to describe the development of PJF associated with rod fractures. Last, thoracic kyphosis was not included in the analysis because we considered that thoracic kyphosis could not be controlled directly by realignment surgery but would be changed reciprocally relative to an increase in LL.

In this study, we demonstrated different risk factors for PJF in different age groups. We concluded that in patients younger than 70 years, a greater change in LL was a single radiographic risk factor regardless of the PI-related value. However, in patients 70 years or older, overcorrection of PI-LL relative to the age-adjusted PI-LL target was an important risk factor for PJF.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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