Spine
SPINE Volume 45, Number 23, pp E1588–E1595

Effects of Restoration of Sagittal Alignment on Adjacent Segment Degeneration in Instrumented Lumbar Fusions

Sang-Il Kim, MD,[a] Hyung-Ki Min, MD,[a] Kee-Yong Ha, MD,[b] Hyung-Youl Park, MD,[c] Chang-Hee Cho, MD,[a] Ryu-Kyoung Cho, MD,[a] and Young-Hoon Kim, MD, PhD[a]

Study Design. Retrospective case-control study.

Objective. To investigate the effects of postoperative sagittal alignment on radiographic adjacent segment degeneration (ASD) after lumbar fusion surgery.

Summary of Background Data. ASD is one of inherent problems with fusion surgery. Many confounding factors are related to the development of ASD. Recently, sagittal alignment has been emphasized for its significance on ASD.

Methods. Seventy-three patients who underwent four-level lumbar fusion surgery (L2–S1) were divided into two groups according to postoperative sagittal alignment (pelvic incidence–lumbar lordosis [PI–LL] $\geq$ or $<9^\circ$): 44 patients (matched group, including 10 patients who underwent pedicle subtraction osteotomy [PSO] at L4) and 29 patients (mismatched group). The general demographics, radiographic parameters, and clinical outcomes were recorded. Preoperative disc degeneration at L1–2 was evaluated by Pfirrmann grade and Kellgren-Lawrence (K-L) grade. Disc degeneration at L1–2 was evaluated by the K-L grade on 2-year postoperative X-rays.

Results. The incidence of radiographic ASD (11 [25%] *vs.* 16 patients [55%], $P=0.02$) and Oswestry Disability Index (ODI) scores (36.9 ± 19.9 *vs.* 49.4 ± 20.7, $P=0.015$) at postoperative 2 years were significantly higher in the mismatched group. There were no significant differences in other demographic and radiographic parameters between the two groups. On subgroup analysis between 10 PSO patients and the mismatched group, the mismatched group showed a higher incidence of radiographic ASD (16 [55%] *vs.* 1 patient [10%], $P=0.041$) and worse ODI scores (49.7 ± 20.5 *vs.* 39.0 ± 20.7, $P=0.040$). Preoperative Pfirrmann grade at L1–2 (odds ratio [OR] = 4.191, 95% confidence interval [CI]: 1.754–10.013, $P=0.001$) and postoperative PI–LL mismatch (OR = 4.890, 95% CI: 1.550–15.427, $P=0.007$) showed significant relationships with the development of radiographic ASD at postoperative 2 years.

Conclusion. The restoration of optimal sagittal alignment, even with PSO, may provide a protective effect on the development of radiographic ASD, although the preoperative disc degeneration grade was a risk factor for radiographic ASD.

Key words: adjacent segment degeneration, intervertebral disc, lumbar, sagittal alignment, spinal fusion.
Level of Evidence: 3
Spine 2020;45:E1588–E1595

Spinal fusion surgery is the treatment of choice for various degenerative spinal disorders refractory to conservative treatment and presents favorable clinical outcomes.[1] However, increased stress on the non-fused adjacent segments after spinal fusion can cause adjacent segment degeneration (ASD). ASD is one of the common complications seen in long-term follow-up after spinal fusion.[2] ASD is a radiographic diagnosis, which is defined as significant radiographic changes in the adjacent segment regardless of the presence of related symptoms. This condition is called as radiographic ASD. Adjacent segment disease refers to ASD requiring revision surgery due to symptoms such as pain or neurologic compromise. This one is also called as symptomatic ASD. The relationship between spinal fusion and ASD has been reported in previous literature. However, the exact incidence or the pathomechanism of ASD remains unclear because many confounding factors exist. Some studies showed that the incidence of ASD following spinal fusion was higher compared with motion-preserving

From the [a]Department of Orthopaedic Surgery, Seoul St. Mary's Hospital, The Catholic University of Korea, Seoul, Republic of Korea; [b]Department of Orthopaedic Surgery, Kyung-Hee University Hospital at Gangdong, Seoul, Republic of Korea; and [c]Department of Orthopaedic Surgery, Eunpyeong St. Mary's Hospital, The Catholic University of Korea, Seoul, Republic of Korea.

Acknowledgment date: March 25, 2020. First revision date: June 11, 2020. Acceptance date: July 8, 2020.

The manuscript submitted does not contain information about medical device(s)/drug(s).

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education(2019R1F1A1063013).

No relevant financial activities outside the submitted work.

Address correspondence and reprint requests to Young-Hoon Kim, MD, PhD, Department of Orthopaedic Surgery, Seoul St. Mary's Hospital, College of Medicine, The Catholic University of Korea, 222, Banpo-daero, Seocho-gu, Seoul, 06591, Republic of Korea;
E-mail: boscoa@catholic.ac.kr

DOI: 10.1097/BRS.0000000000003682

surgeries, but there is insufficient evidence to draw a definitive conclusion.[3,4]

Many risk factors for ASD have already been reported in previous studies and include patient, disease, radiographic, and surgical factors.[2,5,6] Recently, global sagittal spinal alignment, including spinopelvic association, has been emphasized in various spinal pathologies. Moreover, some studies showed the relationship between sagittal balance and ASD.[7,8] A pelvic incidence–lumbar lordosis (PI–LL) mismatch, as an indicator of sagittal malalignment, has been also demonstrated as a risk factor for ASD.[9–12] However, previous studies had some inherent limitations, such as inconsistent fusion levels and non-matched design, so conclusive information is lacking. Therefore, this study was designed to investigate the effect of surgical restoration of sagittal alignment on the development of ASD after limited lumbar fusion by controlling the fusion level.

MATERIALS AND METHODS

Subjects

This was a retrospective case-control study. A flow diagram outlining the subject enrollment is provided in Figure 1. Four hundred twenty-eight patients who underwent at least four-level lumbar fusion surgery were reviewed in a single institute from January 2005 to October 2016. The clinical and radiographic information were analyzed after approval by our Institutional Review Board (IRB approval No. KC18RESI0802). Eighty-eight patients who underwent pedicle subtraction osteotomy (PSO) were also included. The inclusion criteria were age more than 40 years with degenerative lumbar disease, upper instrumented level (UIV) at L2, lower instrumented level (LIV) at the sacrum, and a minimum 2-year follow-up. Therefore, the adjacent segment was consistently L1–2 in all patients. Specific disease entities, such as tumors, infections, or ankylosing spondylitis, were excluded. Patients with preoperative advanced disc degeneration (Kellgren-Lawrence grade $\geq$3) at the adjacent segment (L1–2) and a lack of data within the study period were also excluded. In all patients, posterior segmental fixation using pedicle screws and posterolateral fusion (PLF) was performed. Interbody fusion was selectively performed after individual assessment. Finally, 73 patients were included in the analysis. Based on the postoperative measurement of PI–LL, the patients were divided into two groups, the matched group (PI–LL $<$ 9°) and the mismatched group (PI–LL $\geq$ 9°). Forty-four patients, including 10 patients who underwent PSO, were allocated into the matched group and 29 patients were allocated into the mismatched group. Patient demographic data, such as age, sex, body mass index (BMI), and bone mineral density (BMD) were recorded.

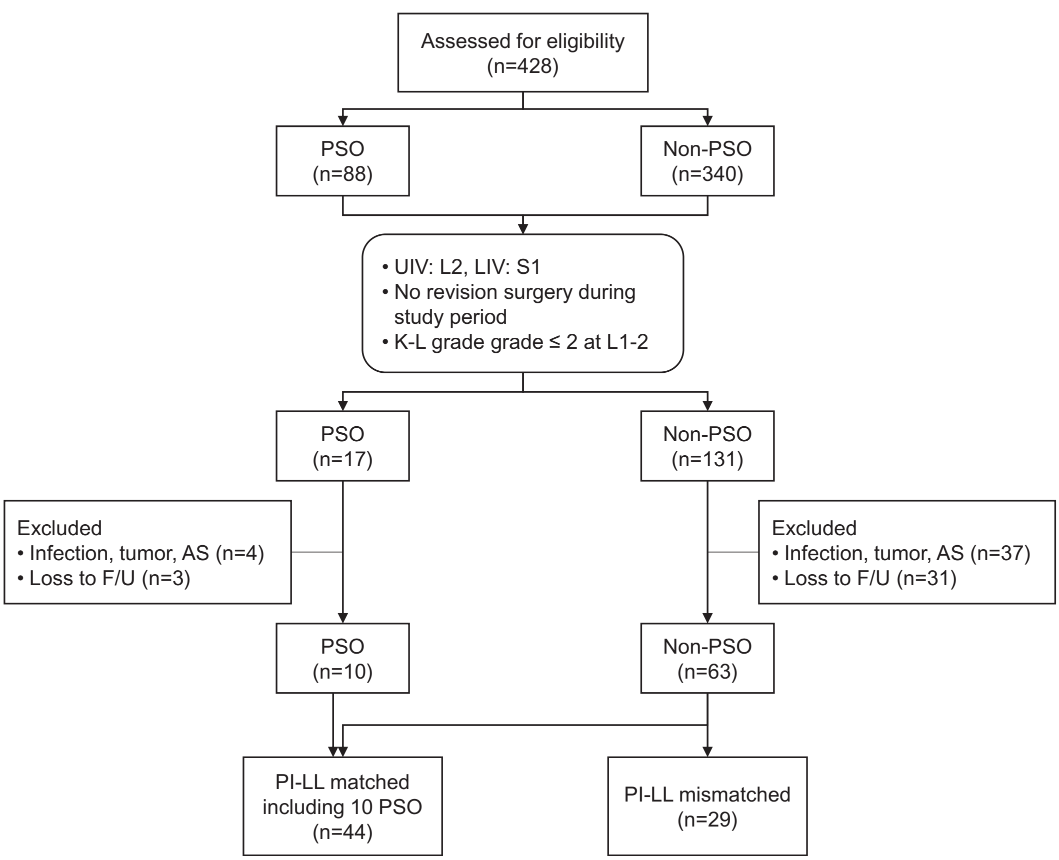

Figure 1. A flow diagram for inclusion and exclusion of the patients.

Clinical and Radiographic Parameters

The clinical assessments were conducted using a numerical rating scale (NRS) and the Oswestry Disability Index (ODI) preoperatively, and 3 months, and 2 years postoperatively. The global spinal alignment was evaluated by coronal Cobb angle, sagittal vertical axis (SVA), T1-pelvic angle (TPA), and other spinopelvic parameters, including LL, PI, thoracic kyphosis (TK), and pelvic tilt (PT). To assess the degree of disc degeneration at L1–2, preoperative magnetic resonance imaging (MRI) and preoperative/postoperative X-rays were investigated. On preoperative MRI, the Pfirrmann grading system was used to evaluate disc status.[13] On lateral lumbar spine X-rays, the Kellgren-Lawrence (K-L) grading system was adopted as follows: grade 0, normal disc with no osteophytes; grade 1, slight anterior wear and osteophyte formation; grade 2, definite anterior wear and mild disc space narrowing with osteophyte formation; grade 3, moderate disc space narrowing with osteophytes and endplate sclerosis; and grade 4, large osteophytes, marked disc space narrowing, and endplate sclerosis. MRI is the most important modality to evaluate the disc status. Pfirrmann *et al*[13] demonstrated that their grading system using MRI is a reliable assessment tool for disc degeneration. However, the postoperative disc status was assessed on plain radiographs because MRI had rarely been performed postoperatively. Radiographic measurement was conducted using preoperative images and 3-month and 2-year postoperative follow-up images. Proximal junctional kyphosis (PJK) at the 2-year follow-up was also investigated. We adopted the definition of PJK by Glattes *et al*.[14] We defined ASD by the following two criteria: (1) K-L grade 3 or 4 at the adjacent segment and (2) deterioration of at least one K-L grade during follow-up compared with the preoperative grade.

Statistical Analysis

The between-group comparison of the baseline data was conducted using the Student *t* test for continuous parameters and Fisher exact test for categorical parameters. Logistic regression analysis was conducted to investigate the risk factors for ASD. The following factors were included as confounding factors: age, BMI, BMD, preoperative Pfirrmann or K-L grade at L1–2, and spinopelvic parameters. Factors with a *P*-value of <0.2 in univariate analysis were included in the multivariate analysis. All statistical analyses were conducted using SPSS 21.0 (SPSS Inc., Chicago, IL).

RESULTS

Baseline Data

There were no significant differences between the two groups in the general demographic and surgical data, including age, sex, BMI, operation time, estimated blood loss, and hospital stay (Table 1). The BMD of the mismatched group was significantly lower than that of the matched group (−3.0 ± 0.9 *vs.* −2.3 ± 1.1, *P* = 0.006). The preoperative Pfirrmann grade for disc degeneration at L1–2 was noted as grade 1, 2, and 3 in 29.5%, 54.5%, and 15.9% of the matched group and 41.4%, 37.9%, and 20.7% of the mismatched group, respectively. The preoperative K-L grade at L1–2 was noted as grade 1 and 2 in 65.9% and 34.1% of the matched group and 51.7% and 48.3% of the mismatched group, respectively. However, there was no significant difference in the preoperative degree of disc degeneration between the two groups (Table 1).

Follow-Up Data

To control the confounding effect of time, the clinical and radiographic data at postoperative 2-years were analyzed. For clinical outcomes, there was a significant difference in the ODI scores at this time point between the two groups (37.4 ± 20.1 in the matched group *vs.* 49.7 ± 20.9 in the mismatched group, *P* = 0.015). However, there were no significant differences in NRS and ODI at preoperative and postoperative 3-months (Table 2). Some sagittal

TABLE 1. Baseline Demographics Between the Matched and Mismatched Groups

	Matched Group (n = 44)	Mismatched Group (n = 29)	*P*
Age, year	67.5 ± 6.7	69.0 ± 6.2	0.325
Sex (female)	34 (77.3%)	27 (93.1%)	0.076
BMI, kg/m^2	24.8 ± 2.7	25.6 ± 3.3	0.299
BMD (T-score)	−2.3 ± 1.1	−3.0 ± 0.9	0.006
Operation time, minute	306.8 ± 72.3	297.9 ± 58.9	0.583
EBL, cm^3	1591.6 ± 909.0	1645.2 ± 948.2	0.809
Hospital stay, day	20.1 ± 10.7	18.5 ± 9.2	0.495
Preoperative Pfirmann grade (L1–2 IVD)			
1	13 (29.5%)	12 (41.4%)	0.606
2	24 (54.5%)	11 (37.9%)	
3	7 (15.9%)	6 (20.7%)	
Preoperative K-L grade (L1–2 IVD)			
1	29 (65.9%)	15 (51.7%)	0.229
2	15 (34.1%)	14 (48.3%)	

BMD indicates bone mineral density; BMI, body mass index; EBL, estimated blood loss; IVD, intervertebral disc; K-L grade, Kellgren-Lawrence grade.

TABLE 2. Clinical Outcomes Between the Matched and Mismatched Groups

	Matched Group (n = 44)	Mismatched Group (n = 29)	*P*
Preoperative			
Back NRS	7.5 ± 2.2	7.0 ± 2.2	0.355
Leg NRS	7.6 ± 2.5	7.1 ± 2.9	0.472
ODI	54.8 ± 16.1	57.9 ± 19.1	0.477
Postoperative			
Back NRS	4.8 ± 2.7	3.9 ± 2.9	0.217
Leg NRS	4.6 ± 3.4	4.3 ± 3.2	0.795
ODI	45.0 ± 21.5	44.5 ± 22.0	0.925
Postoperative 24 months			
Back NRS	4.4 ± 3.2	5.4 ± 3.8	0.247
Leg NRS	4.5 ± 3.2	5.3 ± 3.1	0.281
ODI	37.4 ± 20.1	49.7 ± 20.9	0.015

NRS indicates numerical rating scale; ODI, Oswestry disability index.

parameters, such as PI, PT and PI–LL, SVA, and TPA, were significantly higher in the mismatched group preoperatively and at the postoperative 3-month and 2-year follow-ups. However, there was no significant difference in the coronal Cobb angle. These findings showed that the mismatched group had poorer sagittal balance and higher PI preoperatively. At the postoperative 2-year follow-up, the K-L grades of L1–2 were 1, 2, 3, and 4 in 13.6%, 61.4%, 18.2%, and 6.8% of the matched group and 6.9%, 41.4%, 31%, and 20.7% in the mismatched group, respectively. A significantly higher percentage of grade 3 and 4 degeneration was noted in the mismatched group than in the matched group. Moreover, ASD was significantly more common in the mismatched group (15 patients, 53.3%) than in the matched group (11 patients, 25%). However, there was no significant difference in the PJK incidence (matched group, 15.9%; mismatched group, 17.2%) (Table 3). No cases needed revision surgery due to ASD or PJK in either group during the study period.

To overcome the effect of different preoperative PIs between the two groups, the data of 10 PSO patients were compared with those of the mismatched group. There was no significant difference in the baseline data between the PSO patients and the mismatched group, including clinical parameters and preoperative degree of L1–2 degeneration, except for operation time (Table 4). However, the incidence of ASD was significantly higher in the mismatched group than in the PSO patients. Even though there was no statistical significance, PJK was noted more commonly in PSO patients (40%) compared with the mismatched group (17.2%) (Table 5).

Risk Factors Analysis for ASD

Age, PI–LL mismatch, preoperative Pfirrmann grade, preoperative K-L grade, and postoperative SVA were statistically significant risk factors by univariate analysis ($P < 0.05$). Multivariate analysis of the factors with $P < 0.2$ revealed that the preoperative Pfirrmann grade (odds ratio [OR] = 4.2, 95% confidence interval [CI]: 1.75–10.01, $P = 0.001$) and PI–LL mismatch (OR = 4.9, 95% CI: 1.55–15.42, $P = 0.007$) were significant risk factors.

DISCUSSION

ASD remains one of the long-term complications after spinal fusion surgery, which is considered inevitable. Fusion of mobile segments can increase stress on the adjacent levels subsequent to early degeneration.[15] In a systemic review, the incidence of radiographic ASD after lumbar fusion surgery was 26.6% (95% CI: 21.3%–31.9%) and that of symptomatic ASD was 8.5% (95% CI: 6.4%–10.7%).[16] A number of risk factors for ASD had been reported, including old age, higher body mass index, lower bone mineral density, the number of fused segments, the surgical technique, advanced degeneration of the preoperative paraspinal muscle, adjacent segment disc and facet, and sagittal alignment.[2,6,17–20] Among these risk factors, modifiable factors, such as the number of fused segments, surgical technique, and sagittal alignment, should be considered during preoperative planning to prevent ASD.

Postoperative sagittal alignment is considered critical for favorable surgical outcomes. To obtain optimal sagittal alignment, sufficient lumbar lordosis (LL) is usually required in most adult spinal deformity patients. PI, an anatomical radiographic parameter showing pelvic shape, can help to estimate the optimal LL to obtain spinopelvic alignment.[21] Based on a study by Schwab *et al*,[21] optimal LL is usually targeted to get the difference between PI and LL less than 9. Surgical correction of LL was reported to affect TK reciprocally in a harmonious global spine.[22] In a similar context, Lafage *et al*[23] demonstrated that lumbar PSO with short fusion could lead to an unfavorable reciprocal change in TK, leading to clinical failure. Therefore, we assumed that altered sagittal alignment after limited lumbar fusion could be correlated with the occurrence of juxta-proximal adjacent segment degeneration.

Previous studies have already shown that several sagittal parameters could be a predictor of ASD after lumbar fusion surgery.[7–12] However, these studies had an inherent critical

TABLE 3. Radiographic Outcomes Between the Matched and Mismatched Groups

	Matched Group (n = 44)	Mismatched Group (n = 29)	*P*
Preoperative			
CA	10.6 ± 5.5	12.0 ± 6.0	0.320
PI	45.2 ± 8.8	54.6 ± 11.4	<0.001
PT	20.8 ± 10.1	29.9 ± 8.7	<0.001
SS	24.4 ± 9.0	24.7 ± 9.1	0.868
LL	29.0 ± 17.1	23.2 ± 16.9	0.161
PI–LL	17.8 ± 17.2	31.8 ± 14.2	0.001
TPA	19.6 ± 10.7	29.5 ± 7.7	<0.001
SVA	51.0 ± 46.7	73.7 ± 38.8	0.034
Postoperative			
CA	5.7 ± 3.1	7.5 ± 4.5	0.060
PI	45.7 ± 8.3	55.2 ± 11.4	<0.001
PT	16.8 ± 6.6	26.9 ± 7.1	<0.001
SS	29.0 ± 8.9	28.3 ± 9.0	0.746
LL	41.0 ± 9.5	30.4 ± 11.3	<0.001
PI–LL	6.0 ± 5.0	24.9 ± 7.1	<0.001
TPA	14.9 ± 6.1	24.7 ± 5.8	<0.001
SVA	27.1 ± 28.0	49.0 ± 25.7	0.001
Postoperative 24 months			
CA	6.9 ± 4.9	8.0 ± 4.5	0.375
PI	47.2 ± 10.0	55.5 ± 12.2	0.002
PT	21.4 ± 9.2	30.6 ± 7.7	<0.001
SS	25.7 ± 8.2	24.9 ± 9.6	0.689
LL	31.2 ± 12.7	18.9 ± 14.3	<0.001
PI–LL	16.2 ± 13.1	36.6 ± 12.0	<0.001
TPA	19.7 ± 9.2	31.0 ± 7.4	<0.001
SVA	47.9 ± 34.9	79.1 ± 48.0	0.002
K-L grade			
1	6 (13.6%)	2 (6.9%)	0.019
2	27 (61.4%)	12 (41.4%)	
3	8 (18.2%)	9 (31.0%)	
4	3 (6.8%)	6 (20.7%)	
ASD	11 (25.0%)	15 (53.3%)	0.020
PJK	7 (15.9%)	5 (17.2%)	0.881

ASD indicates adjacent segment degeneration; CA, coronal Cobb angle; K-L grade, Kellgren-Lawrence grade; LL, lumbar lordosis; PI, pelvic incidence; PJK, proximal junctional kyphosis; PT, pelvic tilt; SS, sacral slope; SVA, sagittal vertical axis; TPA, T1-pelvic angle.

limitation that their subjects had inconsistent fusion levels. In contrast, the most important strength of this study was that the authors controlled the fusion level as L2–S1. Therefore, the adjacent segment was identical, at L1–2 in all patients. In this study, the PI–LL matched group showed a significantly lower incidence of ASD compared with the mismatched group at 2-year follow-up (25% *vs.* 53.3%, $P = 0.020$). In logistic regression analysis, PI–LL mismatch, as well as the preoperative Pfirrmann grade at L1–2, was identified as a risk factor with an OR of 4.890 (95% CI: 1.550–15.427, $P = 0.007$). PI–LL mismatch was reported to be strongly associated with the development of adjacent segment disease or degeneration in previous studies.[9,11,12,24] Rothenfluh *et al*[12] showed that patients with PI–LL mismatch (>10°) had a 10-fold higher risk for ASD. PI–LL mismatch can cause compensatory mechanisms, including pelvic retroversion, and eventually lead to global sagittal malalignment. In our cohort, the mismatched group showed predictable sagittal profiles postoperatively (Table 3). In the late 20th century, Jean Dubousset introduced the "cone of economy," which means that ideal spinal alignment allows a standing posture with minimal muscular energy expenditure. Deviation from the boundary of the cone requires greater muscular energy and leads to unfavorable ergonomic outcomes.[21] Senteler *et al*[25] demonstrated that PI–LL mismatch (>15°) induced higher shear stress at the level adjacent to the fused segments in their musculoskeletal simulation study. The authors suggested that the matched group might have less stress on the adjacent disc after the restoration of sagittal balance, leading to less ASD development in this study.

However, the two groups had different preoperative PIs. A study by Nakashima *et al*[26] reported that higher PI was a risk factor for adjacent segment disease. Accordingly,

TABLE 4. Baseline Demographics Between PSO and the Mismatched Groups

	PSO Group (n = 10)	Mismatched Group (n = 29)	*P*
Age, year	65.8 ± 5.3	69.0 ± 6.2	0.155
Sex (female)	10 (100.0%)	27 (93.1%)	0.764
BMI, kg/m^2	24.5 ± 2.2	25.6 ± 3.3	0.372
BMD (T-score)	−2.6 ± 1.3	−3.0 ± 0.9	0.250
Operation time, minute	354.0 ± 71.8	297.9 ± 58.9	0.019
EBL, cm^3	1955.0 ± 1058.9	1645.2 ± 948.2	0.392
Hospital stay, day	23.6 ± 11.6	18.5 ± 9.2	0.163
Preoperative Pfirmann grade (L1–2 IVD)			
1	5 (50.0%)	12 (41.4%)	0.558
2	4 (40.0%)	11 (37.9%)	
3	1 (10.0%)	6 (20.7%)	
Preoperative K-L grade (L1–2 IVD)			
1	9 (90.0%)	15 (51.7%)	0.074
2	1 (10.0%)	14 (48.3%)	

BMD indicates bone mineral density (lowest T-score); BMI, body mass index; EBL, estimated blood loss; IVD, intervertebral disc; K-L grade, Kellgren-Lawrence grade; PSO, pedicle subtraction osteotomy.

TABLE 5. Radiographic Outcomes Between PSO and the Mismatched Groups

	PSO (n = 10)	Mismatched Group (n = 29)	*P*
Preoperative			
CA	8.1 ± 6.3	12.0 ± 6.0	0.167
PI	48.9 ± 12.8	54.6 ± 11.4	0.517
PT	30.7 ± 10.2	29.9 ± 8.7	0.966
SS	18.2 ± 12.4	24.7 ± 9.1	0.364
LL	6.1 ± 15.8	23.2 ± 16.9	0.004
PI–LL	42.7 ± 14.6	31.8 ± 14.2	0.159
TPA	32.5 ± 10.8	29.5 ± 7.7	0.552
SVA	90.7 ± 73.5	73.7 ± 38.8	0.861
Postoperative			
CA	4.3 ± 3.3	7.5 ± 4.5	0.070
PI	50.8 ± 11.8	55.2 ± 11.4	0.521
PT	19.3 ± 8.1	26.9 ± 7.1	0.008
SS	30.5 ± 13.9	28.3 ± 9.0	0.780
LL	42.3 ± 14.7	30.4 ± 11.3	0.007
PI–LL	6.6 ± 3.6	24.9 ± 7.1	<0.001
TPA	15.7 ± 8.6	24.7 ± 5.8	0.001
SVA	19.0 ± 46.2	49.0 ± 25.7	0.203
Postoperative 24 months			
CA	4.3 ± 3.8	8.0 ± 4.5	0.083
PI	52.0 ± 13.6	55.5 ± 12.2	0.643
PT	24.0 ± 11.1	30.6 ± 7.7	0.099
SS	27.9 ± 13.0	24.9 ± 9.6	0.871
LL	27.4 ± 20.8	18.9 ± 14.3	0.566
PI–LL	24.6 ± 18.6	36.6 ± 12.0	0.210
TPA	23.7 ± 12.0	31.0 ± 7.4	0.054
SVA	57.7 ± 41.8	79.1 ± 48.0	0.326
K-L grade			
1	2 (20.0%)	2 (6.9%)	0.041
2	7 (70.0%)	12 (41.4%)	
3	0 (0.0%)	9 (31.0%)	
4	1 (10.0%)	6 (20.7%)	
ASD	1 (10.0%)	15 (53.3%)	0.041
PJK	4 (40.0%)	5 (17.2%)	0.301

ASD indicates adjacent segment degeneration; CA, coronal Cobb angle; K-L grade, Kellgren-Lawrence grade; LL, lumbar lordosis; PI, pelvic incidence; PJK, proximal junctional kyphosis; PSO, pedicle subtraction osteotomy; PT, pelvic tilt; SS, sacral slope; SVA, sagittal vertical axis; TPA, T1-pelvic angle.

subgroup analysis of the PSO group *versus* the mismatched group was performed to exclude the effect caused by differences in PI. These two groups showed no difference in PI (Table 5). Although the number of PSO patients was too small to yield conclusive results, obtaining appropriate LL, even by performing PSO, seems important to reducing the risk of ASD (10% *vs.* 53.3%, $P = 0.041$).

Another risk factor in our study was the preoperative Pfirrmann grade of the adjacent disc. In their biomechanical study, Kim *et al*[27] reported that the intrinsic degeneration of the adjacent disc seemed not to increase annulus fibrosus stress at the adjacent segment after fusion. However, several studies showed that pre-existing adjacent segment degeneration was a risk factor for adjacent segment degeneration and disease.[2,5] Therefore, the fusion extent should be decided after a precise preoperative evaluation of the patient's status.

Interestingly, sagittal parameters such as LL and SVA at the postoperative 2 years decreased in all groups, even more in the PSO patients (Tables 3 and 5). There were two causes of late recurrent sagittal malalignment in our study. First major one was junctional kyphosis at the adjacent L1–2 segment. Compared with ASD, the incidence of PJK was similar between matched and mismatched groups (15.9% *vs.* 17.2%), and even higher in PSO group than mismatched group (40% *vs.* 17.2%). Recurrent sagittal malalignment at the postoperative 2 years may be attributed to the development of compensatory PJK after surgical correction. Recent meta-analysis showed that change in sagittal parameters including LL and SVA were revealed as risk factors for PJK.[28,29] The other one was the late collapse of intervertebral discs within fusion. Authors identified that the heights of intervertebral discs decreased and disc collapse at which interbody fusion was not performed occurred in a kyphotic form. These changes were thought to lead to the decrease in overall LL.

Several limitations exist in this study. First, this was a retrospective study with a relatively small number of patients. Second, the postoperative 2-year was short for the follow-up. Third, the surgical methods were inconsistent. PLF was performed in every patient, but interbody fusion was selectively performed. Interbody fusion is known as a possible risk factor for ASD compared with PLF only. Fourth, this study did not involve postoperative MRI which could provide a standardized assessment of disc status. Finally, clinical outcomes related to ASD were not investigated in out study. Although it is still unclear about the correlation between radiographic ASD and clinical outcomes, no revision surgery was performed in our series during the study period. However, a recent systemic review reported that approximately 30% of radiographic ASD progressed to symptomatic ASD.[2] Therefore, careful follow-up is needed in patients with radiographic ASD.

In conclusion, PI–LL mismatch and preoperative adjacent disc degeneration were risk factors for the development of ASD in patients who underwent L2–S1 fusion. When planning lumbar fusion surgery, obtaining sufficient LL according to PI and proper decision on the fusion extent are crucial to prevent ASD.

➢ Key Points

- ❑ Consecutive patients who underwent spinal fusion surgery from L2 to S1 in a single institute were investigated to compare the incidence of ASD at L1–2 according to postoperative sagittal alignment.
- ❑ Preoperative Pfirrmann disc grade and postoperative PI–LL mismatch were risk factors for ASD development.
- ❑ The restoration of optimal sagittal alignment may provide a protective effect on the development of ASD.

References

1. Oster BA, Kikanloo SR, Levine NL, et al. Systematic review of outcomes following 10-year mark of Spine Patient Outcomes Research Trial (SPORT) for spinal stenosis. *Spine (Phila Pa 1976)* 2019;45:832–6.
2. Hashimoto K, Aizawa T, Kanno H, et al. Adjacent segment degeneration after fusion spinal surgery-a systematic review. *Int Orthop* 2019;43:987–93.
3. Wang JC, Arnold PM, Hermsmeyer JT, et al. Do lumbar motion preserving devices reduce the risk of adjacent segment pathology compared with fusion surgery? A systematic review. *Spine (Phila Pa 1976)* 2012;37:S133–43.
4. Lund T, Oxland TR. Adjacent level disk disease–is it really a fusion disease?. *Orthop Clin North Am* 2011;42:529–41; viii.
5. Zhang C, Berven SH, Fortin M, et al. Adjacent segment degeneration versus disease after lumbar spine fusion for degenerative pathology: a systematic review with meta-analysis of the literature. *Clin Spine Surg* 2016;29:21–9.
6. Lawrence BD, Wang J, Arnold PM, et al. Predicting the risk of adjacent segment pathology after lumbar fusion: a systematic review. *Spine (Phila Pa 1976)* 2012;37:S123–32.
7. Matsumoto T, Okuda S, Maeno T, et al. Spinopelvic sagittal imbalance as a risk factor for adjacent-segment disease after single-segment posterior lumbar interbody fusion. *J Neurosurg Spine* 2017;26:435–40.
8. Radcliff KE, Kepler CK, Jakoi A, et al. Adjacent segment disease in the lumbar spine following different treatment interventions. *Spine J* 2013;13:1339–49.
9. Kim WJ, Ma CH, Kim SH, et al. Prevention of adjacent segmental disease after fusion in degenerative spinal disorder: correlation between segmental lumbar lordosis ratio and pelvic incidence-lumbar lordosis mismatch for a minimum 5-year follow-up. *Asian Spine J* 2019;13:654–62.
10. Phan K, Nazareth A, Hussain AK, et al. Relationship between sagittal balance and adjacent segment disease in surgical treatment of degenerative lumbar spine disease: meta-analysis and implications for choice of fusion technique. *Eur Spine J* 2018;27:1981–91.
11. Tempel ZJ, Gandhoke GS, Bolinger BD, et al. The influence of pelvic incidence and lumbar lordosis mismatch on development of symptomatic adjacent level disease following single-level transforaminal lumbar interbody fusion. *Neurosurgery* 2017; 80:880–6.
12. Rothenfluh DA, Mueller DA, Rothenfluh E, et al. Pelvic incidence-lumbar lordosis mismatch predisposes to adjacent segment disease after lumbar spinal fusion. *Eur Spine J* 2015;24:1251–8.
13. Pfirrmann CW, Metzdorf A, Zanetti M, et al. Magnetic resonance classification of lumbar intervertebral disc degeneration. *Spine (Phila Pa 1976)* 2001;26:1873–8.

14. Glattes RC, Bridwell KH, Lenke LG, et al. Proximal junctional kyphosis in adult spinal deformity following long instrumented posterior spinal fusion: incidence, outcomes, and risk factor analysis. *Spine (Phila Pa 1976)* 2005;30:1643–9.
15. Weinhoffer SL, Guyer RD, Herbert M, et al. Intradiscal pressure measurements above an instrumented fusion. A cadaveric study. *Spine (Phila Pa 1976)* 1995;20:526–31.
16. Xia XP, Chen HL, Cheng HB. Prevalence of adjacent segment degeneration after spine surgery: a systematic review and meta-analysis. *Spine (Phila Pa 1976)* 2013;38:597–608.
17. Ramirez-Villaescusa J, Lopez-Torres Hidalgo J, Martin-Benlloch A, et al. Risk factors related to adjacent segment degeneration: retrospective observational cohort study and survivorship analysis of adjacent unfused segments. *Br J Neurosurg* 2019;33:17–24.
18. Lee CW, Yoon KJ, Ha SS. Which approach is advantageous to preventing development of adjacent segment disease? Comparative analysis of 3 different lumbar interbody fusion techniques (ALIF, LLIF, and PLIF) in L4-5 spondylolisthesis. *World Neurosurg* 2017;105:612–22.
19. Liang J, Dong Y, Zhao H. Risk factors for predicting symptomatic adjacent segment degeneration requiring surgery in patients after posterior lumbar fusion. *J Orthop Surg Res* 2014;9:97.
20. Anandjiwala J, Seo JY, Ha KY, et al. Adjacent segment degeneration after instrumented posterolateral lumbar fusion: a prospective cohort study with a minimum five-year follow-up. *Eur Spine J* 2011;20:1951–60.
21. Schwab F, Patel A, Ungar B, et al. Adult spinal deformity-postoperative standing imbalance: how much can you tolerate? An overview of key parameters in assessing alignment and planning corrective surgery. *Spine (Phila Pa 1976)* 2010;35:2224–31.
22. Jang JS, Lee SH, Min JH, et al. Influence of lumbar lordosis restoration on thoracic curve and sagittal position in lumbar degenerative kyphosis patients. *Spine (Phila Pa 1976)* 2009;34: 280–4.
23. Lafage V, Ames C, Schwab F, et al. Changes in thoracic kyphosis negatively impact sagittal alignment after lumbar pedicle subtraction osteotomy: a comprehensive radiographic analysis. *Spine (Phila Pa 1976)* 2012;37:E180–7.
24. Senteler M, Weisse B, Snedeker JG, et al. Pelvic incidence-lumbar lordosis mismatch results in increased segmental joint loads in the unfused and fused lumbar spine. *Eur Spine J* 2014;23:1384–93.
25. Senteler M, Weisse B, Rothenfluh DA, et al. Fusion angle affects intervertebral adjacent spinal segment joint forces-Model-based analysis of patient specific alignment. *J Orthop Res* 2017;35:131–9.
26. Nakashima H, Kawakami N, Tsuji T, et al. Adjacent segment disease after posterior lumbar interbody fusion: based on cases with a minimum of 10 years of follow-up. *Spine (Phila Pa 1976)* 2015;40:E831–41.
27. Kim HJ, Kang KT, Chun HJ, et al. The influence of intrinsic disc degeneration of the adjacent segments on its stress distribution after one-level lumbar fusion. *Eur Spine J* 2015;24:827–37.
28. Kim JS, Phan K, Cheung ZB, et al. Surgical, radiographic, and patient-related risk factors for proximal junctional kyphosis: a meta-analysis. *Global Spine J* 2019;9:32–40.
29. Zou L, Liu J, Lu H. Characteristics and risk factors for proximal junctional kyphosis in adult spinal deformity after correction surgery: a systematic review and meta-analysis. *Neurosurg Rev* 2019;42:671–82.