Neurospine 2024;21(3):856-864.
https://doi.org/10.14245/ns.2448122.061

Neurospine
pISSN 2586-6583 eISSN 2586-6591

Original Article

Distal Junctional Failure After Fusion Stopping at L5 in Patients With Adult Spinal Deformity: Incidence, Risk Factors, and Radiographic Criteria

Sung Ho Do, Sungsoo Bae, Dae Jean Jo, Ho Yong Choi

Department of Neurosurgery, Kyung Hee University Hospital at Gangdong, Kyung Hee University College of Medicine, Seoul, Korea

Corresponding Author
Ho Yong Choi
https://orcid.org/0000-0002-5545-4283

Department of Neurosurgery, Kyung Hee University Hospital at Gangdong, Kyung Hee University College of Medicine, 892 Dongnam-ro, Gangdong-gu, Seoul 05278, Korea
Email: heoryong83@hanmail.net

Received: February 1, 2024
Revised: July 12, 2024
Accepted: July 13, 2024

See the commentary on "Distal Junctional Failure After Fusion Stopping at L5 in Patients With Adult Spinal Deformity: Incidence, Risk Factors, and Radiographic Criteria" via https://doi.org/10.14245/ns.2448882.441.

Objective: To identify risk factors and establish radiographic criteria for distal junctional failure (DJF) in patients with adult spinal deformity (ASD), who underwent fusion surgery stopping at L5.
Methods: This retrospective study was undertaken from January 2016 to December 2020. Patients with ASD who underwent fusion surgery (≥ 5 levels) stopping at L5 were analyzed. DJF was defined as symptomatic adjacent segment pathology at the lumbosacral junction necessitating consideration for revision surgery. Demographic data and radiographic measurements were compared between the DJF and non-DJF groups. Receiver operating characteristic curve analysis was performed to identify the radiographic cutoff value for DJF.
Results: Among 76 patients, 16 (21.1%) experienced DJF. DJF was associated with older age, antidepressant/anxiolytic medication, longer level of fusions, and worse preoperative sagittal alignment. Antidepressant/anxiolytic medication (odds ratio, 5.60) and preoperative pelvic incidence (PI)–lumbar lordosis (LL) mismatch > 40° (odds ratio, 5.87) were independent risk factors for DJF. Without both factors, the incidence of DJF has been greatly reduced (9.1%). Two radiographic criteria were determined for DJF: last distal junctional angle (DJA) > -5° and Δ last DJA–post DJA > 5°. When both criteria were met, the sensitivity and specificity of the DJF were 93.3% and 91.7%, respectively.
Conclusion: Use of antidepressant/anxiolytic medication and preoperative PI–LL mismatch > 40° were independent risk factors for DJF. DJF could be diagnosed using postoperative changes in the DJA. If both criteria were met, DJF could be strongly suggested.

Keywords: Adult spinal deformity, Junctional spine disorder, Distal junctional failure, Distal junctional kyphosis, Adjacent segment disease, Complications

INTRODUCTION

Among the mechanical complications after long fusion surgery in patients with adult spinal deformity (ASD), junctional problems are the most significant.[1,2] Particularly, distal junctional problems have a greater clinical impact, such as increased sagittal decompensation or reoperation rates, than proximal counterparts, including proximal junctional kyphosis/failure (PJK/PJF) (Fig. 1).[3,4] Nevertheless, research on distal junctional problems has not been widely reported, in contrast to research conducted on PJK/PJF. Previous studies on distal junctional problems have primarily focused on pediatric populations with conditions such as adolescent idiopathic scoliosis or Scheuermann's kyphosis and have mainly investigated kyphosis occurring at the thoracolumbar junction or upper lumbar level, creating a gap in the understanding of junctional problems in patients with ASD, who usually have instrumentation at the lumbosacral junction.

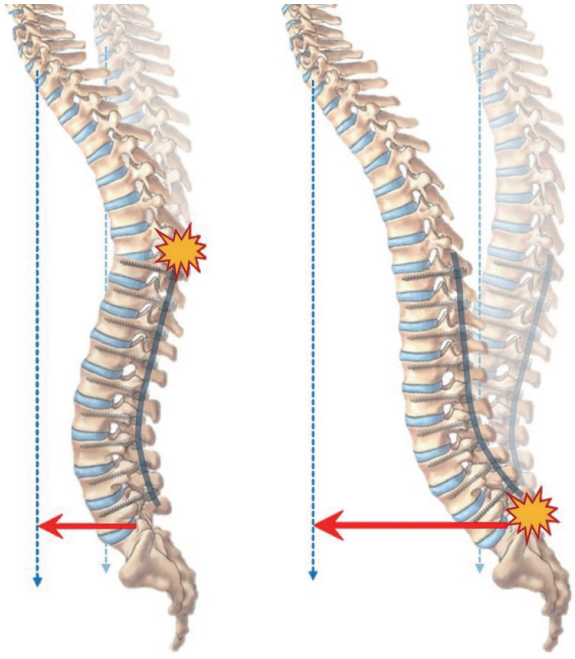

Fig. 1. Diagrams depicting the effect of sagittal decompensation after junctional kyphosis. Assuming that kyphosis of 20° has occurred at each proximal and distal junction, distal junctional kyphosis results in greater sagittal imbalance compared with its proximal counterpart.

Reports on distal junctional problems in patients with ASD include mainly comparative studies on surgical outcomes when instrumentation is stopped at L5 or S1, with inconsistent results regarding complications and revision surgery rates.[4-6] Instrumentation stopping at L5 has been reported to be associated with a high frequency of subsequent disc degeneration at the L5–S1 disc (60%–70%). However, it is unclear whether this was a natural degeneration or true pathologic process because there was no relevant control group. Moreover, confounding factors for distal junctional failure (DJF) were not adequately adjusted for.[7,8] The clinical impact of subsequent disc degeneration was also unclear.[5,7,8]

Recently, McDonnell et al.[9] reported that more than 40% of patients with ASD suffered from DJF in the postoperative period. They concluded that pedicle subtraction osteotomy (PSO), poor correction of lumbar lordosis (LL), and sagittal vertical axis (SVA) were independent risk factors for DJF. However, they included all mechanical problems occurring at the distal end, even in surgeries involving sacropelvic fixation, as DJF. In cases of PJK/PJF, which can be considered counterparts to distal junctional kyphosis (DJK)/DJF, a significant proportion of failures (over 30%) occur at the noninstrumented mobile segment (such as the junctional disc, ligament, or uninstrumented adjacent vertebrae), in addition to failures that occur at the UIV.[10,11] It is inappropriate to discuss DJF in cases of sacropelvic fixation because there is no adjacent mobile segment present in such cases. Therefore, we investigated DJF in patients with ASD, who underwent long fusion surgery stopping at L5, exclusively.

Nowadays, even if the L5–S1 disc is relatively healthy, instrumentation extending to the pelvis has become a common practice in ASD surgeries, because of concerns regarding the subsequent degeneration at the L5–S1 disc. However, pelvic fixation is associated with substantial complications such as fixation failure, painful implant, and increased risk of PJK.[12-16] Furthermore, it could further restrict the activities of daily living of patients due to the longer construct, compared with preservation of the lumbosacral junction.[17-19]

In this study, we evaluated the patients with ASD who underwent long fusion surgery stopping at L5 and compared the parameters between the DJF and non-DJF groups. We aimed to identify the independent risk factors and establish the radiographic criteria for DJF.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board of Kyung Hee University Hospital at Gangdong (KHNMC 2023-03-001). The requirement for informed consent was waived because this study was retrospective cohort study on chart review and involved minimal risks to the subjects. From January 2016 to December 2020, the medical records of consecutive adult (aged >18 years) patients with ASD, who underwent long fusion surgery stopping at L5 were reviewed retrospectively. Patients with a fusion of 5 or more segments (upper instrumented vertebra at or above L1) were included. The minimum follow-up period was 2 years after surgery. Patients who underwent grade ≥3 osteotomy (e.g., PSO or vertebral column resection) were excluded. Patients who underwent surgery for posttuberculous kyphosis, infectious etiology, or scoliosis associated with idiopathic or syndromic etiology were also excluded. Patients with a radiographic evidence suggestive of the lumbosacral transitional vertebra, or an incomplete preoperative radiographic study (e.g., absent whole-spine standing radiographs) were also excluded. Finally, patients with significant deformities involving the L5–S1 disc (oblique takeoff) were excluded. We defined the significant oblique takeoff as the intercrestal line subtended by a horizontal plane >15°.[20,21]

Patients with persistent (≥3 months) back or lower extremity pain, disability, or neurological deficits (e.g., lower extremity

weakness) were considered candidates for surgical treatment. All patients underwent a staged operation that was a posterior approach for instrumentation and facetectomy and/or laminectomy in the first stage. Thereafter, an oblique retroperitoneal approach followed by oblique lateral interbody fusion and posterior rod assembly in the second stage. L5 laminar hooks were applied in most cases (80.3%) to augment L5 screws. All patients wore a brace for 3 months after surgery. Moreover, rehabilitation therapy was provided concurrently in cases of neurological deficits (e.g., ankle weakness) or prolonged difficulties with walking.

DJF was defined as adjacent segment pathology (i.e., disc degeneration, instability, stenosis, facet degeneration, fracture, and deformity) at the lumbosacral junction accompanied by clinical deterioration necessitating consideration for revision surgery. We did not define DJF based on the junctional angle because no consistent angle criterion applies to patients with ASD. This definition was referenced form the definition of PJF, determined by Yagi et al.,[11] which could be considered as the counterpart of DJF. Finally, a total of 76 patients were enrolled and divided into the DJF and non-DJF groups.

Demographic data, including age, sex, body mass index (BMI), comorbidities, American Society of Anesthesiologists (ASA) physical status classification, medication, bone mineral density (measured using dual-energy x-ray absorptiometry), follow-up period, history of prior lumbar fusion including L5, and the number of fused vertebrae, were evaluated. Operative data were evaluated in terms of surgical time, surgical bleeding, and the length of hospital stay. The radiographic measurements were performed by 2 neurosurgeons who did not participate in the surgery. Spinopelvic parameters, including pelvic incidence (PI), LL, PI–LL mismatch, thoracolumbar angle (TL), pelvic tilt (PT), the SVA, and coronal curve characteristics were measured from whole-spine standing radiographs preoperatively, postoperatively (within 1 month), and at the last follow-up. The LL was defined as the angle between the L1 superior endplate and S1 superior endplate. We measured L4–S1 lordosis as the angle between the L4 superior endplate and S1 superior endplate. The distal junctional angle (DJA) was defined as the angle between the L5 inferior endplate and S1 superior endplate on standing radiographs. In the DJF group, the last radiographic parameter was measured at the time of DJF occurrence. Detailed radiographic characteristics of the L5–S1 discs were assessed in terms of Weiner classification, Pfirrmann grade, modified Pfirrmann grade, disc height, disc angle, and segmental motion (disc angle between flexion and extension). The L5–S1 disc angle was measured in both the supine and standing positions, and the change in angle according to the position was also measured. Negative values represented lordosis, whereas positive values represented kyphosis.

We used IBM SPSS Statistics ver. 25.0 (IBM Co., Armonk, NY, USA) for statistical analysis. The independent t-test and Mann-Whitney U-test were employed to compare the means of the parametric and nonparametric variables, respectively. The normality of the data was determined using the Shapiro-Wilk and Kolmogorov-Smirnov tests. The chi-square and Fisher exact tests were used for dichotomous data analyses. To identify the predictive factors for DJF, we performed multivariable binary logistic regression analysis for potential predictors with p-values of <0.05 in univariable analysis. Odds ratios (ORs), 95% confidence intervals (95% CIs), and p-values were calculated. Receiver operating characteristic (ROC) curve analysis, including the area under the curve (AUC), was performed to identify the radiographic cutoff value for the occurrence of DJF. A p-value of <0.05 was considered statistically significant.

RESULTS

1. Comparison of DJF and Non-DJF Groups

Among the 76 patients, 16 (21.1%) experienced DJF and were recommended revision surgery. The median time to DJF occurrence was 2.4 years (range, 0.5–4.5 years). Eventually, 8 patients underwent fusion extension to the pelvis, 7 refused revision surgery, and 1 was unable to undergo revision surgery due to a poor general condition (cerebral infarction). The most common type of DJF was junctional kyphosis with endplate sclerosis or disruption (n = 6), followed by progression of sagittal imbalance (n = 5). Other types of DJF included disc space collapse with foraminal stenosis (n = 3) and junctional compression fractures (L5 or S1; n = 2).

The DJF group was significantly older than the non-DJF group (73.4 ± 5.0 years vs. 69.7 ± 6.4 years, p = 0.034) (Table 1). The proportion of patients with a history of taking antidepressant/anxiolytic medication was higher in patients with DJF than in those without (37.5% vs. 10.0%, p = 0.015). Other demographic parameters, including sex, BMI, Charlson comorbidity index, ASA classification, antiplatelet medication, osteoporosis, follow-up period, and the number of interbody fusion, did not differ between the groups, except the number of fused vertebrae (7.1 ± 1.1 vs. 6.3 ± 1.3, p = 0.037). Surgical details such as surgical time (284.8 ± 85.1 minutes vs. 293.1 ± 54.8 minutes, p = 0.636), surgical bleeding (931.3 ± 262.6 mL vs. 928.3 ± 242.2 mL, p = 0.967), and the length of hospital stay (20.9 ± 8.3 days vs. 19.5 ± 7.8 days,

https://doi.org/10.14245/ns.2448122.061

Table 1. Demographic data of patients with adult spinal deformity who underwent long fusion surgery stopping at L5

Variable	DJF (n = 16)	Non-DJF (n = 60)	p-value
Age (yr)	73.4 ± 5.0	69.7 ± 6.4	0.034
Sex, male:female	3:13	19:41	0.371
Body mass index (kg/m^2)	25.3 ± 3.2	25.6 ± 4.0	0.718
Charlson comorbidity index	4.0 ± 1.5	3.3 ± 1.3	0.100
ASA PS classification (n)	2.1 ± 0.7	2.1 ± 0.5	0.805
Antiplatelet medication (%)	50.0	33.3	0.219
Antidepressant/anxiolytic medication (%)	37.5	10.0	0.015
Osteoporosis (%)	43.8	41.5	1.000
BMD (g/cm^2)	-2.1 ± 1.3	-1.6 ± 1.5	0.263
Follow-up period (yr)	3.1 ± 1.1	3.2 ± 1.1	0.775
No. of interbody fusion	3.0 ± 0.5	3.1 ± 0.5	0.511
No. of fused vertebrae	7.1 ± 1.1	6.3 ± 1.3	0.037

Values are presented as mean ± standard deviation unless otherwise indicated.
DJF, distal junctional failure; ASA PS, American Society of Anesthesiologists physical status; BMD, bone mineral density.

Table 3. Preoperative L5–S1 radiographic characteristics in patients with adult spinal deformity who underwent long fusion surgery stopping at L5

Variable	DJF (n = 16)	Non-DJF (n = 60)	p-value
Weiner classification	1.9 ± 1.0	1.8 ± 1.0	0.664
Pfirrmann grade	3.9 ± 0.5	4.0 ± 0.7	0.798
Modified Pfirrmann grade	5.3 ± 1.2	5.3 ± 1.4	0.549
Anterior disc height (mm)	14.9 ± 3.9	15.3 ± 5.4	0.814
Posterior disc height (mm)	6.0 ± 1.7	6.8 ± 2.4	0.140
Mean disc height (mm)	10.5 ± 2.6	11.1 ± 3.6	0.567
Disc angle (°)	-14.4 ± 4.7	-13.6 ± 5.6	0.593
Segmental motion (°)			
ΔFlexion–extension	7.8 ± 4.6	7.5 ± 4.2	0.811
ΔSupine–standing	3.3 ± 8.1	0.1 ± 5.5	0.009

Values are presented as mean ± standard deviation.
DJF, distal junctional failure.

p = 0.566) did not differ between the 2 groups.

The perioperative spinopelvic parameters are summarized in Table 2. PI and coronal curve magnitude did not differ between the groups. Most preoperative radiographic parameters of sagittal alignment were significantly worse in the DJF group than in the non-DJF group in terms of LL (-2.4° ± 28.0° vs. -22.2° ± 17.5°, p = 0.015), PI–LL mismatch (51.7° ± 29.1° vs. 29.8° ± 20.0°,

Table 2. Radiographic characteristics of patients with adult spinal deformity who underwent long fusion surgery stopping at L5

Variable	DJF (n = 16)	Non-DJF (n = 60)	p-value
Coronal curve magnitude (n)			0.960
< 10°	8	31	
10°–30°	5	14	
> 30°	3	15	
Pelvic incidence (°)	54.1 ± 10.1	52.0 ± 10.8	0.484
Lumbar lordosis (°)			
Preoperative	-2.4 ± 28.0	-22.2 ± 17.5	0.015
Postoperative	-37.5 ± 9.9	-44.5 ± 12.0	0.038
Last	-22.4 ± 19.4	-43.2 ± 13.6	< 0.001
L4–S1 lordosis (°)			
Preoperative	-16.6 ± 17.1	-23.3 ± 13.5	0.098
Postoperative	-13.8 ± 9.9	-21.5 ± 10.0	0.008
Last	-1.3 ± 19.0	-21.7 ± 11.9	< 0.001
Pelvic incidence–lumbar lordosis (°)			
Preoperative	51.7 ± 29.1	29.8 ± 20.0	0.011
Postoperative	16.5 ± 12.6	7.3 ± 13.0	0.013
Last	32.5 ± 22.7	8.7 ± 16.7	0.001
Thoracolumbar angle (°)			
Preoperative	23.1 ± 25.1	14.7 ± 16.6	0.223
Postoperative	10.0 ± 13.7	10.6 ± 10.7	0.839
Last	9.5 ± 12.6	13.0 ± 12.4	0.328
Pelvic tilt (°)			
Preoperative	29.7 ± 11.7	24.0 ± 9.2	0.041
Postoperative	23.3 ± 10.6	19.0 ± 8.7	0.095
Last	19.0 ± 10.6	18.1 ± 11.9	0.804
Sagittal vertical axis (mm)			
Preoperative	169.6 ± 107.1	92.6 ± 80.6	0.002
Postoperative	54.9 ± 38.1	28.2 ± 35.6	0.010
Last	191.7 ± 90.4	53.9 ± 51.6	< 0.001

Values are presented as mean ± standard deviation unless otherwise indicated.
DJF, distal junctional failure.

p = 0.011), PT (39.7° ± 11.7° vs. 24.0° ± 9.2°, p = 0.041), and SVA (169.6 ± 107.1 mm vs. 92.6 ± 80.6 mm, p = 0.002). Patients with DJF also showed markedly worse sagittal alignment at the last follow-up than the non-DJF group, in terms of LL (-22.4° ± 19.4° vs. -43.2° ± 13.6°, p < 0.001), L4–S1 lordosis (-1.3° ± 19.0° vs. -21.7° ± 11.9°, p < 0.001), and SVA (191.7 ± 90.4 mm vs. 53.9 ± 51.6 mm, p < 0.001).

We assessed the detailed preoperative radiographic charac-

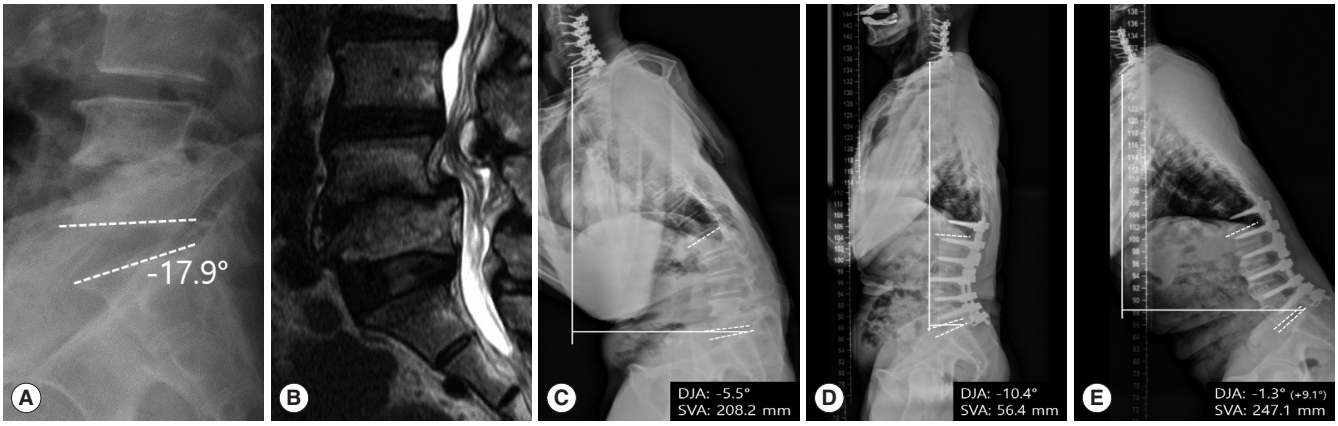

Fig. 2. A 64-year-old man presenting with a progressively stooped posture and pain in the back and lower extremities. (A) Degenerative changes in the L5–S1 disc is mild (Weiner classification 1) with well-preserved disc height and angle (-17.9°). (B) Magnetic resonance imaging showing a clear distinction between the annulus and nucleus of the L5–S1 disc (Pfirrmann grade 3). (C) Preoperative standing radiograph showing sagittal malalignment with lumbar kyphosis (24.2°) and sagittal vertical axis (SVA) of 208.2 mm. The pelvic incidence (PI) is 52.1° and preoperative PI–LL (lumbar lordosis) mismatch is 76.3°, which is greater than 40° (cutoff value). (D) After long fusion surgery stopping at L5, sagittal malalignment shows improvement with SVA of 56.4 mm. (E) Two years and 6 months after the surgery, there is development of distal junctional failure with severe sagittal malalignment (SVA, 247.1 mm). The last distal junctional angle (DJA) is -1.3° and increased by 9.1° from the postoperative DJA.

Table 4. Changes in the distal junctional angle in patients with adult spinal deformity who underwent long fusion surgery stopping at L5

Variable	DJF (n = 16)	Non-DJF (n = 60)	p-value
Preoperative DJA (°)	-11.1 ± 9.1	-13.6 ± 6.8	0.239
Postoperative DJA (°)	-5.7 ± 6.3	-8.4 ± 6.1	0.125
Last DJA (°)	6.0 ± 14.3	-9.3 ± 7.9	0.001
ΔLast DJA–preoperative DJA (°)	16.1 ± 19.2	4.3 ± 6.3	0.029
ΔLast DJA–postoperative DJA (°)	10.7 ± 11.8	-0.9 ± 4.8	0.001

Values are presented as mean ± standard deviation.
DJF, distal junctional failure; DJA, distal junctional angle.

teristics of the L5–S1 disc space (Table 3). The degree of disc degeneration in terms of the Weiner classification, Pfirrmann grade, and modified Pfirrmann grade did not differ between the groups. Other radiographic parameters, such as disc height, disc angle, and segmental motion between flexion and extension, did not differ between the groups. However, the mean change in the disc angle between the supine and standing postures was significantly greater in the DJF group than in the non-DJF group (3.3° ± 8.1° vs. 0.1° ± 5.5°, p = 0.009) (Fig. 2).

Perioperative changes in the DJA significantly differed between the groups (Table 4). The DJA at the last follow-up (last DJA) was significantly greater (kyphotic) in the DJF group than in the non-DJF group (6.0° ± 14.3° vs. -9.3° ± 7.9°, p = 0.001). The amount of changes in the last DJA from preoperative DJA (pre DJA, 16.1° ± 19.2° vs. 4.3° ± 6.3°, p = 0.029) and from postoperative DJA (post DJA, 10.7° ± 11.8° vs. -0.9° ± 4.8°, p = 0.001) were also significantly greater in the DJF group than in the non-DJF group (Fig. 3).

2. Identification of Risk Factors for DJF

To identify preoperative risk factors for DJF, we conducted multivariable logistic regression analysis in terms of potential predictors, including age, antidepressant/anxiolytic medication, number of fused vertebrae, LL, TL, PT, SVA, PI–LL mismatch, and the difference in disc angle between supine and standing postures. Consequently, antidepressant/anxiolytic medication (OR, 4.96; 95% CI, 1.09–22.62; p = 0.039) and preoperative PI–LL mismatch (OR, 1.04; 95% CI, 1.01–1.07; p = 0.009) were identified as risk factors for DJF.

The preoperative sagittal parameters, including LL, TL, PT, SVA, and PI–LL mismatch, were divided in a dichotomous fashion for brevity and clarity, based on an ROC curve analysis. The optimal cutoff values were determined as follows: LL = -15°, TL = 20°, PT = 30°, SVA = 100 mm, PI–LL mismatch = 40°. All of these values were statistically significant. As a result of the multivariable logistic regression analysis, antidepressant/anxiolytic medication (OR, 5.60; 95% CI, 1.26–24.81; p = 0.023) and preoperative PI–LL mismatch > 40° (OR, 5.87; 95% CI, 1.66–20.81; p = 0.006) were identified as risk factors for DJF. When

https://doi.org/10.14245/ns.2448122.061

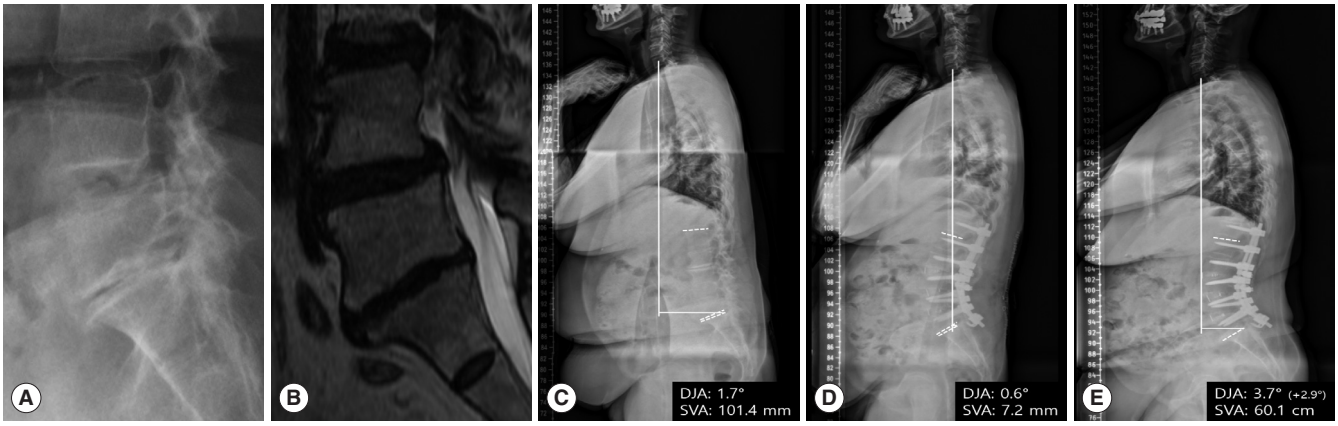

Fig. 3. A 60-year-old woman presenting with pain in her back and left lower extremity, and intermittent claudication. (A) A plain radiograph showing advanced degeneration of the L5–S1 disc with severe narrowing of disc space, marked eburnation, and the presence of gas (Weiner classification 3). (B) Magnetic resonance imaging also showing severe disc degeneration with a collapsed disc space (Pfirrmann grade 5). (C) A preoperative standing radiograph showing sagittal malalignment with decreased lumbar lordosis (LL, -15.1°) and sagittal vertical axis (SVA) of 101.4 mm. The pelvic incidence (PI) is 47.3° and preoperative PI–LL mismatch is 32.2°, which is less than 40° (cutoff value). (D) After long fusion surgery from T12 to L5, sagittal malalignment shows improvement (LL, -51.2°; SVA, 7.2 mm). (E) Four years and 6 months after the surgery, she was doing well without developing distal junctional failure. The last distal junctional angle (DJA) is 3.7° and increased by 2.9° from the postoperative DJA.

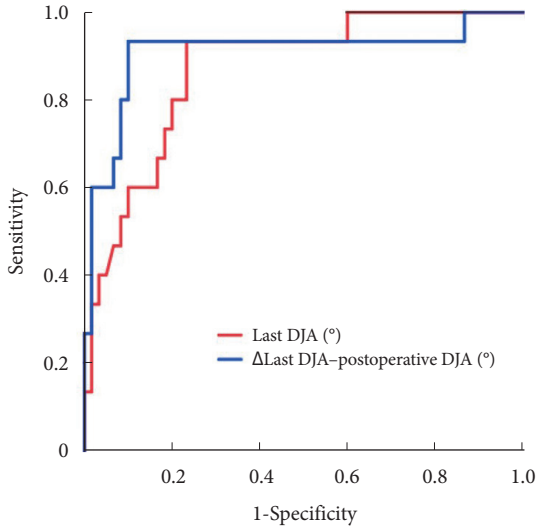

Fig. 4. Receiver operating characteristic curve of the last distal junctional angle (DJA) and Δlast DJA–post DJA to identify radiographic cutoff values for distal junctional failure (DJF). The area under the curve values for the last DJA and Δlast DJA–post DJA are 0.871 ($p < 0.001$) and 0.908 ($p < 0.001$), respectively. The optimal cutoff values for DJF are -5° for the last DJA and 5° for Δlast DJA–post DJA.

these 2 factors were present, the incidence of DJF was 71.4%. On the other hand, without both of these factors, the incidence of DJF was greatly reduced (9.1%).

3. Radiographic Criteria for DJF

We conducted a ROC curve analysis to identify the optimal radiographic cutoff values for the diagnosis of DJF using 2 parameters: (1) last DJA and (2) Δlast DJA–post DJA (Fig. 4). The AUC values for the last DJA and Δlast DJA–post DJA were 0.871 ($p < 0.001$) and 0.908 ($p < 0.001$), respectively. Consequently, the optimal cutoff values for DJF were determined to be -5° for the last DJA and 5° for Δlast DJA–post DJA. We calculated sensitivity and specificity for the diagnosis of DJF using the last DJA > -5° (criterion A) and Δlast DJA–post DJA > 5° (criterion B). When both A and B were met, the sensitivity and specificity of the DJF were 93.3% and 91.7%, respectively.

DISCUSSION

In the present study, DJF occurred in 16 out of 76 patients (21.1%) with ASD, after long fusion surgery stopping at L5. The principal findings were as follows: First, patients with DJF were older (73.4 years vs. 69.7 years), took antidepressant/anxiolytic medication more frequently (37.5% vs. 10.0%), and underwent longer fusion (7.1 vs. 6.3), than did those without DJF. Regarding radiographic parameters, the DJF group had worse preoperative sagittal alignment, such as LL, PI–LL mismatch, PT, and SVA. Second, the use of antidepressant/anxiolytic medication and preoperative PI–LL mismatch (> 40°) were identified as independent risk factors for DJF. When both these factors were

absent, the incidence of DJF was less than 10%. Therefore, stopping at L5 can be considered to avoid the potential complications associated with pelvic fixation in patients without risk factors. Finally, DJF could be effectively diagnosed based on the postoperative changes in DJA. Therefore, we propose 2 radiographic criteria for DJF: last DJA > -5° and Δlast DJA–post DJA > 5°. If both criteria are met, DJF should be suspected (93.3% sensitivity and 91.7% specificity).

In cases of ASD undergoing long fusion surgery, many studies have reported the advantages of performing sacropelvic fixation. However, we believe that in certain cases (e.g., healthy lordotic L5–S1 disc or almost collapsed disc space with little segmental motion), consideration of stopping at L5 remains still valuable. The benefits of sparing the L5–S1 segment include the following: (1) Sparing the motion segment can reduce the stiffness experienced by patients and be advantageous for activities of daily living.[17,22,23] It is known that the longer the instrumentation, the greater the stiffness perceived by the patient.[18] (2) Sacropelvic fixation increases stress and strain on the construct, which is a known risk factors for PJK/PJF.[15,24] Additionally, issues related to sacropelvic fixation, such as increased surgical time, blood loss, and the prominence of iliac screws, can arise.[12,19] Stopping at L5 can mitigate these issues. Therefore, in cases of patients with ASD, without significant segmental instability or nerve root compression, we consistently deliberate on the option of stopping the fusion at L5.

It is noteworthy that the risk of DJF increased about 6 times in patients with a history of taking antidepressant/anxiolytic medication. This finding is consistent with previous studies that highlighted that depression and anxiety, the most common affective disorders, have been reported as risk factors for poor outcomes after spinal surgery in terms of functional recovery and postoperative pain scale.[25-27] Toombs et al.[28] also reported that mood and anxiety disorders were independent risk factors for device-related complications in patients with ASD. They hypothesized that worse outcomes may be related to patient compliance, the effect of medications on overall health, and postoperative recovery. Therefore, it is suggested that poor functional recovery and defective rehabilitation may be associated with DJF. However, further research will be necessary to clarify the precise causal relationship.

Interestingly, the degree of L5–S1 disc degeneration evaluated using plain radiography and magnetic resonance imaging (MRI) was not associated with the occurrence of DJF. These results are inconsistent with the current recommendations that stopping at L5 is reasonable if the L5–S1 disc is healthy and there is no instability or major deformity.[7,8,29] One explanation for this discrepancy may be the paradox that the potential for future degeneration of healthy discs can be higher than the risk of further degeneration of an already degenerated disc. Another explanation is that the current grading systems measured using plain radiographs or MRI do not sufficiently reflect the true degenerative changes in the disc. In this study, postural change (Δsupine-standing) of disc angle was significantly greater in the DJF group than in the non-DJF group (3.3° vs. 0.1°). We suppose that, unlike the supine position without axial loading, a greater decrease in the lordotic angle in the standing posture may reflect the structural vulnerability of the L5–S1 disc in patients with DJF.

We defined DJF based on symptomatic failure at the adjacent segment, without considering the junctional angle because there were no reliable or consistent results for the angular criterion. This definition was referenced from the definition of PJF determined by Yagi et al.,[11] which could be considered as the counterpart of DJF. In previous studies, the angular criterion for DJK was either DJA > 10° or DJA increase > 10° or both.[2,30,31] Another study defined DJK based on the disc angle as kyphotic change.[32,33] Moreover, most studies have evaluated pediatric populations in whom the lowest instrumented vertebra (LIV) is mostly located at the thoracolumbar junction (which normally has little lordosis or even kyphosis).[30-33] Therefore, it is unreasonable to apply similar criteria in patients with ASD, in whom almost all LIV are located at the lumbosacral junction (which normally has significant lordosis). Based on the ROC curve results, DJF appears to occur with a smaller change in the junctional angle than PJK/PJF. Consequently, we propose new radiographic criteria for DJF (last DJA > -5°, Δlast DJA–post DJA > 5°). Although DJF is strongly suggested when both criteria are met, clinicians should be aware of the possibility of DJF even when either of these criteria is met.

Notably, the DJA was measured between the inferior (not superior) endplate of L5 and the superior endplate of S1. Although most previous studies measured DJA as the angle between the superior endplate of the LIV and the inferior endplate of the LIV–1,[2,32,33] we found that it was difficult to discern the superior endplate of L5 in substantial cases for the following reasons: (1) The superior endplate of L5 overlapped with the iliac crest. (2) In contrast to pediatric patients, fusion with the interbody cage was frequently performed at the most distal segment (L4–5) in patients with ASD. Subsequent bony trabeculation, cage subsidence, or pseudarthrosis reduced the clarity of the superior endplate of L5. Therefore, we consider that the measurement of

 https://doi.org/10.14245/ns.2448122.061

the DJA, as the angle between the inferior endplate of L5 and the superior endplate of S1, is more appropriate.

This study had some limitations. First, it was retrospective in nature and therefore is likely to have inherent challenges such as selection bias and confounding factors. Second, although this was the largest study conducted to date, the cohort was not large enough to perform logistic regression analysis without the risk of overfitting. We believe that this issue can be addressed by a larger sample size, which can be accomplished with future multicenter studies involving a larger number of patients. Lastly, due to severe pain and poor general condition, a substantial number of patients could not complete the detailed outcome measures. The lack of patient-reported outcome measures was another limitation.

Although these limitations were noteworthy, this study also had its own strengths. First, we noticed that applying the DJK angle criteria from prior studies on pediatric patients to patients with ASD was inappropriate because the anatomical characteristics of the distal junction were different. Second, to evaluate the true junctional failures at the noninstrumented mobile segment (such as the junctional disc, ligament, or uninstrumented adjacent vertebrae), we only included patients that underwent surgery stopping at L5, rather than sacropelvic fixation. Consequently, we think long fusion surgery stopping at L5 may be acceptable in patients with ASD, without risk factors. However, when the patient is taking antidepressant/anxiolytic medication or has preoperative PI–LL mismatch >40°, sacropelvic fixation should be considered to avoid postoperative DJF.

CONCLUSION

The incidence of DJF was 21.1% in patients with ASD, who underwent fusion surgery stopping at L5. The use of antidepressant/anxiolytic medication and preoperative PI–LL mismatch >40° were independent risk factors for DJF. Without both factors, the incidence of DJF was greatly reduced (9.1%). DJF can be diagnosed based on postoperative changes in the DJA. If both criteria (last DJA > -5°, Δlast DJA–post DJA > 5°) are met, DJF should be strongly suspected.

NOTES

Conflict of Interest: The authors have nothing to disclose.

Funding/Support: This study received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Acknowledgments: We would like to express our gratitude to Seon Hwa Lee, a medical statistician, for her valuable assistance with the statistical analysis.

Author Contribution: Conceptualization: DJJ, HYC; Data curation: SB, HYC; Formal analysis: HYC; Methodology: HYC; Project administration: DJJ, HYC; Visualization: HYC; Writing – original draft: SHD, SB; Writing – review & editing: SHD, HYC.

ORCID

Sung Ho Do: 0009-0003-0267-0964
Sungsoo Bae: 0009-0001-1868-1698
Dae Jean Jo: 0000-0003-3304-3931
Ho Yong Choi: 0000-0002-5545-4283

REFERENCES

1. Teles AR, Aldebeyan S, Aoude A, et al. Mechanical complications in adult spinal deformity surgery: can spinal alignment explain everything? Spine (Phila Pa 1976) 2022;47:E1-9.
2. Yilgor C, Sogunmez N, Boissiere L, et al. Global alignment and proportion (GAP) score: development and validation of a new method of analyzing spinopelvic alignment to predict mechanical complications after adult spinal deformity surgery. J Bone Joint Surg Am 2017;99:1661-72.
3. Cho KJ, Suk SI, Park SR, et al. Risk factors of sagittal decompensation after long posterior instrumentation and fusion for degenerative lumbar scoliosis. Spine (Phila Pa 1976) 2010;35:1595-601.
4. Taneichi H, Inami S, Moridaira H, et al. Can we stop the long fusion at L5 for selected adult spinal deformity patients with less severe disability and less complex deformity? Clin Neurol Neurosurg 2020;194:105917.
5. Cho KJ, Suk SI, Park SR, et al. Arthrodesis to L5 versus S1 in long instrumentation and fusion for degenerative lumbar scoliosis. Eur Spine J 2009;18:531-7.
6. Edwards CC 2nd, Bridwell KH, Patel A, et al. Long adult deformity fusions to L5 and the sacrum. A matched cohort analysis. Spine (Phila Pa 1976) 2004;29:1996-2005.
7. Edwards CC 2nd, Bridwell KH, Patel A, et al. Thoracolumbar deformity arthrodesis to L5 in adults: the fate of the L5-S1 disc. Spine (Phila Pa 1976) 2003;28:2122-31.
8. Kuhns CA, Bridwell KH, Lenke LG, et al. Thoracolumbar deformity arthrodesis stopping at L5: fate of the L5-S1 disc, minimum 5-year follow-up. Spine (Phila Pa 1976) 2007;32:2771-6.

9. McDonnell JM, Evans SR, Ahern DP, et al. Risk factors for distal junctional failure in long-construct instrumentation for adult spinal deformity. Eur Spine J 2022;31:3654-61.
10. Hart R, McCarthy I, O'Brien M, et al. Identification of decision criteria for revision surgery among patients with proximal junctional failure after surgical treatment of spinal deformity. Spine (Phila Pa 1976) 2013;38:E1223-7.
11. Yagi M, Rahm M, Gaines R, et al. Characterization and surgical outcomes of proximal junctional failure in surgically treated patients with adult spinal deformity. Spine (Phila Pa 1976) 2014;39:E607-14.
12. Guler UO, Cetin E, Yaman O, et al. Sacropelvic fixation in adult spinal deformity (ASD); a very high rate of mechanical failure. Eur Spine J 2015;24:1085-91.
13. Ilyas H, Place H, Puryear A. A comparison of early clinical and radiographic complications of iliac screw fixation versus S2 alar iliac (S2AI) fixation in the adult and pediatric populations. J Spinal Disord Tech 2015;28:E199-205.
14. Kim YH, Ha KY, Chang DG, et al. Relationship between iliac screw loosening and proximal junctional kyphosis after long thoracolumbar instrumented fusion for adult spinal deformity. Eur Spine J 2020;29:1371-8.
15. Park WM, Choi DK, Kim K, et al. Biomechanical effects of fusion levels on the risk of proximal junctional failure and kyphosis in lumbar spinal fusion surgery. Clin Biomech (Bristol, Avon) 2015;30:1162-9.
16. Choi HY, Hyun SJ, Kim KJ, et al. Freehand S2 alar-iliac screw placement using K-Wire and cannulated screw: technical case series. J Korean Neurosurg Soc 2018;61:75-80.
17. Ishikawa Y, Miyakoshi N, Kobayashi T, et al. Activities of daily living and patient satisfaction after long fusion for adult spinal deformity: a retrospective study. Eur Spine J 2019;28:1670-7.
18. Kimura H, Fujibayashi S, Otsuki B, et al. Effects of lumbar stiffness after lumbar fusion surgery on activities of daily living. Spine (Phila Pa 1976) 2016;41:719-27.
19. Choi HY, Jo DJ. Utilization of S1 foraminal hooks for augmentation of S1 screws in adult spinal deformity surgery: comparative study with iliac screws. Neurospine 2021;18:554-61.
20. Dayer R, Ouellet JA, Saran N. Pelvic fixation for neuromuscular scoliosis deformity correction. Curr Rev Musculoskelet Med 2012;5:91-101.
21. Modi HN, Suh SW, Song HR, et al. Evaluation of pelvic fixation in neuromuscular scoliosis: a retrospective study in 55 patients. Int Orthop 2010;34:89-96.
22. Hart RA, Marshall LM, Hiratzka SL, et al. Functional limitations due to stiffness as a collateral impact of instrumented arthrodesis of the lumbar spine. Spine (Phila Pa 1976) 2014;39:E1468-74.
23. Yoshida G, Boissiere L, Larrieu D, et al. Advantages and disadvantages of adult spinal deformity surgery and its impact on health-related quality of life. Spine (Phila Pa 1976) 2017;42:411-9.
24. Bridwell KH, Lenke LG, Cho SK, et al. Proximal junctional kyphosis in primary adult deformity surgery: evaluation of 20 degrees as a critical angle. Neurosurgery 2013;72:899-906.
25. Aalto TJ, Malmivaara A, Kovacs F, et al. Preoperative predictors for postoperative clinical outcome in lumbar spinal stenosis: systematic review. Spine (Phila Pa 1976) 2006;31:E648-63.
26. Adogwa O, Verla T, Thompson P, et al. Affective disorders influence clinical outcomes after revision lumbar surgery in elderly patients with symptomatic adjacent-segment disease, recurrent stenosis, or pseudarthrosis: clinical article. J Neurosurg Spine 2014;21:153-9.
27. Nayar G, Elsamadicy AA, Zakare-Fagbamila R, et al. Impact of affective disorders on recovery of baseline function in patients undergoing spinal surgery: a single institution study of 275 patients. World Neurosurg 2017;100:69-73.
28. Toombs CS, Paul JC, Lonner BS. Psychosocial factors and surgical outcomes in adult spinal deformity: do dementia patients have more complications? Spine (Phila Pa 1976) 2018;43:1038-43.
29. Swamy G, Berven SH, Bradford DS. The selection of L5 versus S1 in long fusions for adult idiopathic scoliosis. Neurosurg Clin N Am 2007;18:281-8.
30. Denis F, Sun EC, Winter RB. Incidence and risk factors for proximal and distal junctional kyphosis following surgical treatment for Scheuermann kyphosis: minimum five-year follow-up. Spine (Phila Pa 1976) 2009;34:E729-34.
31. Lowe TG, Lenke L, Betz R, et al. Distal junctional kyphosis of adolescent idiopathic thoracic curves following anterior or posterior instrumented fusion: incidence, risk factors, and prevention. Spine (Phila Pa 1976) 2006;31:299-302.
32. Cho KJ, Lenke LG, Bridwell KH, et al. Selection of the optimal distal fusion level in posterior instrumentation and fusion for thoracic hyperkyphosis: the sagittal stable vertebra concept. Spine (Phila Pa 1976) 2009;34:765-70.
33. Zhu W, Sun X, Pan W, et al. Curve patterns deserve attention when determining the optimal distal fusion level in correction surgery for Scheuermann kyphosis. Spine J 2019;19:1529-39.

 https://doi.org/10.14245/ns.2448122.061