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Fusion Length Requiring Spinopelvic Fixation in Lumbosacral Fusion with Anterior Column Support at L5–S1: Assessment of Fusion Status Using Computed Tomography

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Background: The lumbosacral (LS) junction has a higher nonunion rate than other lumbar segments, especially in long-level fusion. Nonunion at L5–S1 would result in low back pain, spinal imbalance, and poor surgical outcomes. Although anterior column support at L5–S1 has been recommended to prevent nonunion in long-level LS fusion, fusion length requiring additional spinopelvic fixation (SPF) in LS fusion with anterior column support at L5–S1 has not been evaluated thoroughly. This study aimed to determine the number of fused levels requiring SPF in LS fusion with anterior column support at L5–S1 by assessing the interbody fusion status using computed tomography (CT) depending on the fusion length.

Methods: Patients who underwent instrumented LS fusion with L5–S1 interbody fusion without additional augmentation and CT > 1 year postoperatively were included. The fusion rates were assessed based on the number of fused segments. Patients were divided into two groups depending on the L5–S1 interbody fusion status: those with union vs. those with nonunion. Binary logistic regression analyses were performed to identify risk factors for LS junctional nonunion.

Results: Fusion rates of L5–S1 interbody fusion were 94.9%, 90.3%, 80.0%, 50.0%, 52.6%, and 43.5% for fusion of 1, 2, 3, 4, 5, and ≥ 6 levels, respectively. The number of spinal levels fused ≥ 4 ($p < 0.001$), low preoperative bone mineral density (BMD; adjusted odds ratio [aOR], 0.667; $p = 0.035$), and postoperative pelvic incidence (PI) – lumbar lordosis (LL) mismatch (aOR, 1.034; $p = 0.040$) were identified as significant risk factors for nonunion of L5–S1 interbody fusion according to the multivariate logistic regression analysis.

Conclusions: Exhibiting ≥ 4 fused spinal levels, low preoperative BMD, and large postoperative PI–LL mismatch were identified as independent risk factors for nonunion of anterior column support at L5–S1 in LS fusion without additional fixation. Therefore, SPF should be considered in LS fusion extending to or above L2 to prevent LS junctional nonunion.

Keywords: *Lumbosacral region, Pseudarthrosis, Spinal fusion, Spinopelvic fixation*

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Despite considerable advances in surgical techniques and instrumentation, nonunion at L5–S1 remains a significant challenge for spine surgeons due to poor bone quality of the sacrum, the complex regional anatomy, substantial biomechanical forces at the lumbosacral (LS) junction, and large cantilever effect of the long construct.[1,2] To prevent LS pseudarthrosis and fixation failure, several surgical strategies, including spinopelvic fixation (SPF) including

iliac screw (IS) and S2–alar–IS (S2AIS), multiple sacral screws, four-rod technique, and anterior column support, have been recommended, especially for long-level fusion including the LS junction.[2-5] The risk for nonunion and fixation failure at the LS junction is generally believed to increase as the number of fused levels increases.[2,5,6]

Despite several studies investigating the fusion length requiring SPF, definite indications have yet to be established. While some authors have suggested that instrumented LS fusion extending to or above L2 requires additional stronger fixation,[5,7] others have proposed it in cases of fusion extending to L3.[8] Lee et al.[5] reported that the nonunion rate at the LS junction increased significantly for > 3 levels by evaluating fusion status in instrumented fusion with and without anterior column support using plain radiography.

To assess fusion status, plain radiography relies on segmental motion, progression of deformity, and fixation failure, including rod or screw breakage, screw loosening, screw pullout, or rod dislodgement, rather than bony fusion itself.[9,10] Moreover, it is difficult to clearly determine interbody fusion status inside the disc space using only plain radiography.[11] Hence, there may have been patients who had pseudarthrosis before the occurrence of fixation failure at the time of evaluation in previous studies. Meanwhile, computed tomography (CT) is a more sophisticated and sensitive modality than plain radiography in assessing fusion.[12]

To the best of our knowledge, no previous study has evaluated the fusion length necessitating additional fixation among patients with instrumented LS fusion with anterior column support at L5–S1. Therefore, this study aimed to determine the number of fused levels requiring SPF by evaluating interbody fusion status at the LS junction using CT depending on fusion length in patients who underwent LS fusion without additional stronger fixation. We also aimed to analyze several factors that likely affect L5–S1 interbody fusion, including bone quality, spinal alignment, and quantified status of the paraspinal muscles.

METHODS

Study Patients

This retrospective study was approved by the Institutional Review Board of the hospital (No. K2022-0948-001). Due to the retrospective design of the study and the use of anonymized patient data, requirements for informed consent were waived. The medical records of all consecutive patients, who underwent instrumented fusion including interbody fusion at L5–S1 without any additional augmentation, such as IS and S2AIS, between February 2011 and October 2021 at a single institution, were reviewed. Patients who were followed up for ≥ 12 months and underwent an LS CT scan ≥ 1 year postoperatively were included. Individuals who underwent surgery for trauma or spinal infection, those with postoperative development of surgical site infection, those with ankylosing spondylitis, and those with incomplete medical record documentation were excluded. Moreover, patients with high-grade spondylolisthesis, slippage of the vertebral body (VB) relative to the adjacent caudal VB > 50% (Meyerding grade III to V), were also excluded because it differs from other lumbar degenerative diseases (LDD) in terms of pathology, exceptional mechanical forces, and surgical planning.[13,14] Included patients were divided into two groups: those with union and those with nonunion at L5–S1.

Patients were treated for various LDD, including spinal stenosis without spondylolisthesis, spondylolisthesis (degenerative or spondylolytic) with central and/or foraminal stenosis, adult spinal deformity, and posterior spinal surgery syndrome after previous lumbar surgeries not involving fusion at L5–S1. All patients underwent anterior lumbar interbody fusion (ALIF) or posterior lumbar interbody fusion (PLIF) at L5–S1. Polyetheretherketone cages filled with allogenic cancellous bone and demineralized bone matrix for ALIF or autologous local bone plus demineralized bone matrix for PLIF were inserted. All fused segments were instrumented using pedicle screws.

Data Collection

Data regarding patient demographics (sex, age, height, body weight, and body mass index), preoperative bone mineral density (BMD), current smoking status, comorbidities (diabetes mellitus, hypertension, and liver disease), degree of atrophy and fat infiltration of the paraspinal muscles, preoperative diagnosis, number of levels fused, and radiological parameters were collected. Regarding the number of levels fused, patients were classified into 6 categories, from those with 1-level fusion to those with ≥ 6-level fusion. Radiological parameters included pelvic incidence (PI), lumbar lordosis (LL), PI–LL mismatch, pelvic tilt (PT), sacral slope (SS), and sagittal vertical axis (SVA) using standing neutral plain radiographs obtained preoperatively and immediate postoperatively. Regarding the immediate postoperative radiological parameters, we assessed the postoperative 2- to 4-week radiographs to exclude the effect of the postoperative pain or decline of general condition right after the operation on the sagittal balance. Suboptimal SVA was defined as ≥ 4 cm.[15]

Evaluation of Fusion Status and the Paraspinal Muscles

The L5–S1 interbody fusion status was classified into a 4-grade system using LS CT performed at a minimum of 1 year postoperatively as follows: grade 1, fusion with complete remodeling and trabeculae across the disc space; grade 2, intact graft partially remodeled and incorporated without lucent lines; grade 3, intact graft with a definite lucent line between the graft and adjacent endplates; and grade 4, absence of fusion with resorption of the graft material (Fig. 1).[16] Grades 1 and 2 were defined as bone union and grades 3 and 4 as nonunion.

To evaluate the degree of atrophy and fat infiltration of the paraspinal muscles, axial T2-weighted magnetic resonance images (MRI) at the lower endplate of L3 were analyzed using a Picture Archiving and Communication System (Infinitt). After establishing the region of interest (ROI) by outlining the boundary of the paraspinal muscles (multifidus and erector spinae), the cross-sectional area (CSA) and signal intensity (SI) of the paraspinal muscles were measured to assess muscle atrophy and fat infiltration, respectively.[17] To minimize the bias caused by differences in individual physiques, the relative CSA was measured by dividing the CSA of the paraspinal muscles by that of the VB at the same level.[18] The SI of the fatty streak within the ROI was measured using a histogram, and the mean SI value was extracted. To minimize bias depending on the individual, relative fat infiltration was determined by dividing the mean SI of the paraspinal muscles by that of the subcutaneous fat and then multiplying by 100 (Fig. 2).[17]

Statistical Analysis

A comparative analysis was performed to identify any statistical differences between patients with union and those with nonunion at L5–S1 using Student *t*-test (mean ± standard deviation) or the Mann-Whitney test (median, interquartile range) for continuous variables and chi-square test or the Fisher's exact test for categorical variables. Univariate analyses were performed for all variables using binary logistic regression analysis. A multivariate binary logistic regression analysis was performed to identify independent risk factors for L5–S1 nonunion using variables with $p < 0.2$ according to univariate analysis. We used a stepwise

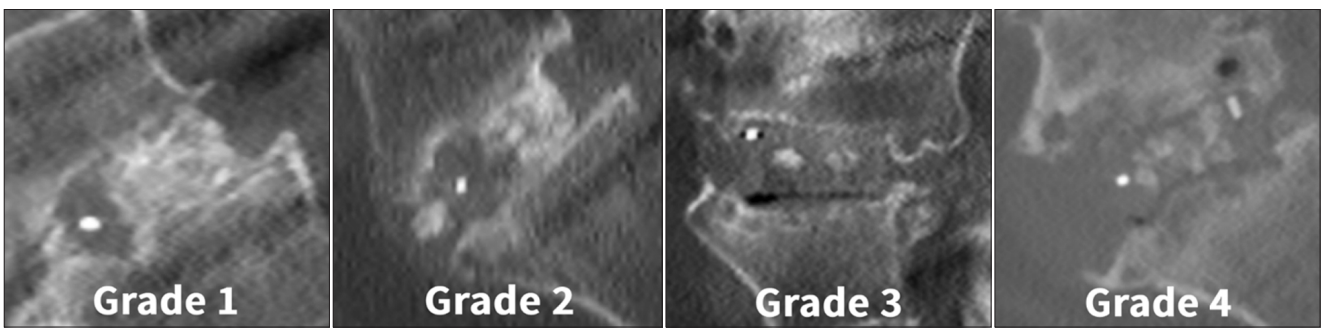

Fig. 1. Four-grade system for interbody fusion status using computed tomography scan: grade 1, complete remodeling with trabeculae across the disc space; grade 2, intact graft without lucent lines between endplates and the graft; grade 3, intact graft with a lucent line between endplates and the graft; and grade 4, absence of fusion with resorption of the graft material.

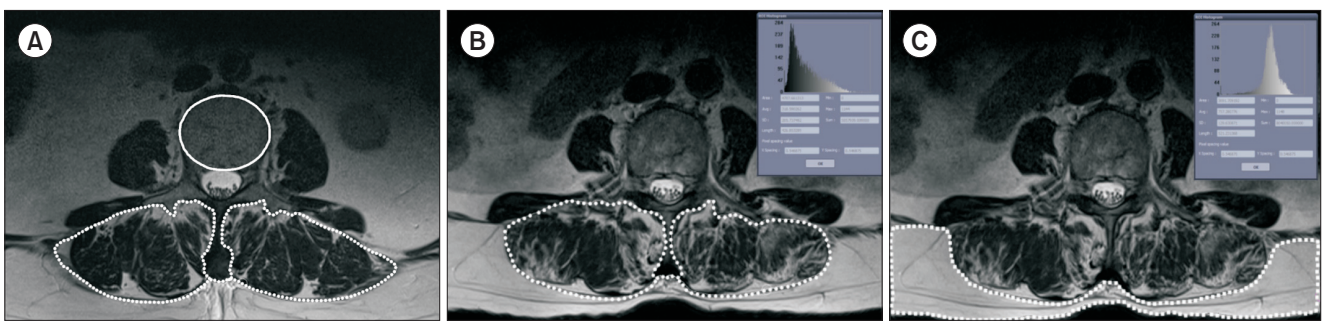

Fig. 2. Assessment of the degree of atrophy and fat infiltration of the paraspinal muscles by establishing the region of interest. (A) Measurement of the relative cross-sectional area (CSA) by dividing the CSA of the paraspinal muscles (dotted line) by that of the vertebral body (solid line). (B) Measurement of the mean signal intensity (SI) of the paraspinal muscles (dotted line) using a histogram. (C) Measurement of the mean SI of the subcutaneous fat (dotted line).

method and applied an entry condition of $p < 0.05$ and a removal condition of $p > 0.1$; the final model included only statically significant variables (i.e., those with $p < 0.05$). The adjusted odds ratios (aOR) and corresponding 95% confidence intervals (CI) were calculated. Statistical significance was set at $p < 0.05$. All statistical analyses were performed using IBM SPSS ver. 25.0 (IBM Corp.).

RESULTS

Baseline Characteristics and Fusion Rates

A total of 222 consecutive patients who underwent instrumented fusion surgeries including L5–S1 interbody fusion without SPF and were followed up for ≥ 12 months were identified. Patients who underwent surgery for trauma (n = 1) or spinal infection (n = 6), those who experienced surgical site infection postoperatively (n = 5), and those with ankylosing spondylitis (n = 1), high-grade spondylolisthesis (n = 2), and incomplete documentation (n = 32) were excluded, leaving 175 patients (130 women; mean age, 69.7 ± 8.9 years) (Fig. 3). Preoperative diagnoses included the following: lumbar spinal stenosis without spondylolisthesis (n = 89); degenerative spondylolisthesis (n = 50); spondylolytic spondylolisthesis (n = 37); adult spinal deformity (n = 29), and posterior spinal surgery syndrome after previous lumbar surgery without fusion at L5–S1 (n = 30). Some of the patients had multiple preoperative diagnoses.

The overall incidence of nonunion at L5–S1 was

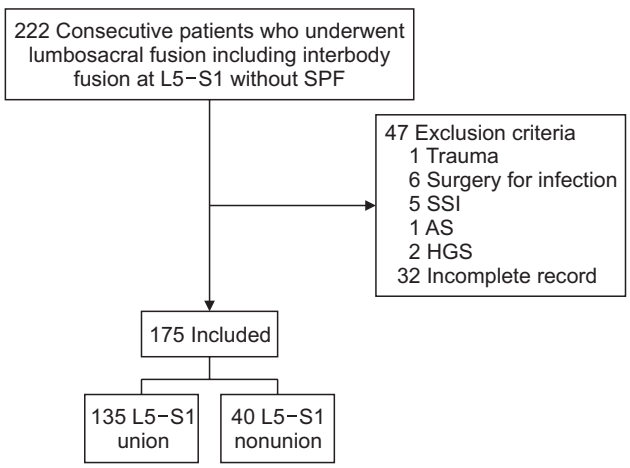

Fig. 3. Flow diagram for this study. SPF: spinopelvic fixation, SSI: surgical site infection, AS: ankylosing spondylitis, HGS: high-grade spondylolisthesis.

Table 1. Fusion Rates of Interbody Fusion at L5–S1 According to the Number of Levels Fused

Number of levels fused	Number of patients		Fusion rate (%)
	Union	Nonunion	
1	37	2	94.9
2	56	6	90.3
3	16	4	80.0
4	6	6	50.0
5	10	9	52.6
≥ 6	10	13	43.5
Total	135	40	77.1

Table 2. Comparison of Baseline Characteristics between Patients with Union and Nonunion at L5–S1

Variable	Union (n = 135)	Nonunion (n = 40)	*p*-value
Age (yr)	69 ± 9	72 ± 8	0.160*
Sex			0.906†
Female	100 (74.1)	30 (75.0)	
Male	35 (25.9)	10 (25.0)	
Height (cm)	1.56 (1.49–1.60)	1.54 (1.48–1.60)	0.596‡
Body weight (kg)	59.4 (51.9–67.9)	60.0 (54.6–73.7)	0.414‡
BMI (kg/m^2)	25.2 (22.2–27.4)	26.0 (23.5–28.1)	0.214‡
BMD (T-score)	–1.5 ± 1.3	–2.0 ± 1.1	0.023*,‖
Comorbidity			
Diabetes	50 (37.0)	10 (25.0)	0.159†
Hypertension	91 (67.4)	24 (60.0)	0.386†
Liver disease	1 (0.7)	2 (5.0)	0.131§
Current smoking	17 (12.6)	8 (20.0)	0.240†
Number of levels fused			< 0.001†,‖
1	37 (27.4)	2 (5.0)	
2	56 (41.5)	6 (15.0)	
3	16 (11.9)	4 (10.0)	
4	6 (4.4)	6 (15.0)	
5	10 (7.4)	9 (22.5)	
≥ 6	10 (7.4)	13 (32.5)	

Values are presented as mean ± standard deviation, number (%), or median (interquartile range).
BMI: body mass index, BMD: bone mineral density.
*Student *t*-test. †Chi-square test. ‡Mann-Whitney test. §Fisher's exact test. ‖Statistically significant ($p < 0.05$).

22.9% (40/175). Fusion rates were 94.9%, 90.3%, 80.0%, 50.0%, 52.6%, and 43.5% for fusion of 1, 2, 3, 4, 5, and ≥ 6 levels, respectively ($p < 0.001$) (Table 1). The mean follow-up duration was 28.8 ± 25.8 months.

Comparison of Patients with Union and Nonunion at L5–S1

Comparing patients with union (n = 40) and nonunion (n = 135) at L5–S1, the proportions of fusion length were significantly different ($p < 0.001$). Patients with nonunion at L5–S1 exhibited a significantly lower T-score for BMD than those with union (–2.0 ± 1.1 vs. –1.5 ± 1.3, respectively; $p = 0.023$) (Table 2).

Regarding preoperative radiological parameters, patients with nonunion at L5–S1 exhibited significantly smaller LL (15.2 ± 21.1 vs. 28.6 ± 18.6, $p < 0.001$) and larger PI–LL mismatch (36.7 ± 19.0 vs. 23.3 ± 18.8, $p < 0.001$) and PT (28.7 ± 11.9 vs. 23.6 ± 10.9, $p < 0.001$) than those with union. Additionally, the nonunion group exhibited a significantly higher proportion of preoperative suboptimal SVA than the union group (85.0% vs. 58.5%, $p = 0.002$). The nonunion group also had significantly smaller postoperative LL (27.9 ± 15.6 vs. 33.6 ± 11.4, $p = 0.034$) and larger PI–LL mismatch (24.0 ± 16.0 vs. 18.3 ± 11.9, $p = 0.040$) and PT (20.9 ± 9.2 vs. 17.8 ± 8.0, $p = 0.036$) than the union group (Table 3).

Table 3. Comparison of Radiological Parameters between Patients with Union and Nonunion at L5–S1

Variable	Union (n = 135)	Nonunion (n = 40)	*p*-value
Preoperative			
PI (°)	52.9 ± 10.9	51.9 ± 12.7	0.983*
LL (°)	28.6 ± 18.6	15.2 ± 21.1	< 0.001*,‡
PI–LL mismatch (°)	23.3 ± 18.8	36.7 ± 19.0	< 0.001*,‡
PT (°)	23.6 ± 10.9	28.7 ± 11.9	0.012*,‡
SS (°)	28.2 ± 11.5	23.1 ± 12.8	0.018*,‡
Suboptimal SVA	79 (58.5)	34 (85.0)	0.002†,‡
Postoperative			
LL (°)	33.6 ± 11.4	27.9 ± 15.6	0.034*,‡
PI–LL mismatch (°)	18.3 ± 11.9	24.0 ± 16.0	0.040*,‡
PT (°)	17.8 ± 8.0	20.9 ± 9.2	0.036*,‡
SS (°)	31.2 ± 8.9	29.6 ± 9.2	0.322*
rCSA of paraspinal muscle	3.6 ± 0.8	3.5 ± 1.1	0.683*
rFI of paraspinal muscle (%)	35.5 ± 11.4	39.3 ± 10.7	0.060*

Values are presented as mean ± standard deviation or number (%).
PI: pelvic incidence, LL: lumbar lordosis, PT: pelvic tilt, SS: sacral slope, SVA: sagittal vertical axis, rCSA: relative cross-sectional area, rFI: relative fat infiltration.
*Student *t*-test. †Chi-square test. ‡Statistically significant ($p < 0.05$).

Table 4. Univariate Analysis of Risk Factors for Nonunion of Interbody Fusion at L5–S1

Variable	Crude odds ratio	95% CI	*p*-value
Age	1.031	0.988–1.076	0.160
Sex	1.050	0.466–2.367	0.906
Height	0.994	0.973–1.016	0.573
Body weight	1.010	0.989–1.031	0.345
BMI	1.000	0.995–1.006	0.922
BMD	0.691	0.500–0.955	0.025*
Diabetes	0.567	0.256–1.257	0.162
Current smoking	1.735	0.687–4.384	0.244
Number of levels fused			< 0.001*
2 vs.1	1.982	0.379–10.355	0.417
3 vs.1	4.625	0.768–27.863	0.095
4 vs.1	18.500	3.004–113.949	0.002*
5 vs.1	16.650	3.091–89.686	0.001*
≥ 6 vs.1	24.050	4.645–124.534	< 0.001*
Preoperative PI	1.000	0.969–1.032	0.983
Preoperative LL	0.966	0.947–0.984	< 0.001*
Preoperative PI–LL mismatch	1.035	1.016–1.055	< 0.001*
Preoperative PT	1.040	1.008–1.074	0.015*
Preoperative SS	0.964	0.934–0.994	0.020*
Preoperative suboptimal SVA	4.017	1.580–10.211	0.003*
Postoperative LL	0.965	0.938–0.993	0.014*
Postoperative PI–LL mismatch	1.034	1.006–1.063	0.017*
Postoperative PT	1.047	1.002–1.094	0.038*
Postoperative SS	0.980	0.942–1.020	0.320
rCSA of paraspinal muscle	0.904	0.603–1.353	0.623
rFI of paraspinal muscle	1.029	0.998–1.061	0.063

CI: confidence interval, BMI: body mass index, BMD: bone mineral density, PI: pelvic incidence, LL: lumbar lordosis, PT: pelvic tilt, SS: sacral slope, SVA: sagittal vertical axis, rCSA: relative cross-sectional area, rFI: relative fat infiltration.
*Statistically significant ($p < 0.05$).

Table 5. Multivariate Analysis of Risk Factors for Nonunion of Interbody Fusion at L5–S1

Variable	Adjusted odds ratio	95% CI	*p*-value
Number of levels fused			< 0.001*
2 vs.1	1.609	0.299–8.644	0.579
3 vs.1	3.300	0.526–20.718	0.203
4 vs.1	20.947	3.149–139.350	0.002*
5 vs.1	11.363	2.000–64.554	0.006*
≥ 6 vs.1	21.703	4.045–116.450	<0.001*
BMD	0.667	0.458–0.971	0.035*
Postoperative PI–LL mismatch	1.034	1.002–1.068	0.040*

CI: confidence interval, BMD: bone mineral density, PI: pelvic incidence, LL: lumbar lordosis.
*Statistically significant ($p < 0.05$).

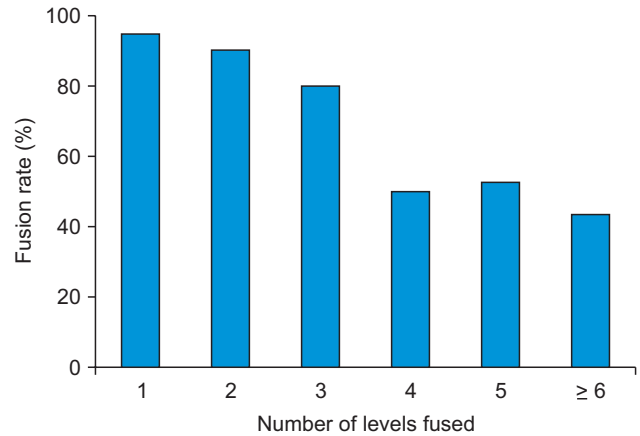

Fig. 4. Fusion rates based on the number of levels fused.

Logistic Regression Analysis: Risk Factor Analysis

Significant factors associated with the nonunion of the L5–S1 interbody fusion, determined using univariate analyses, were the number of spinal levels fused ($p < 0.001$), BMD (crude OR [cOR], 0.691; $p = 0.025$), preoperative LL (cOR, 0.966; $p < 0.001$), preoperative PI–LL mismatch (cOR, 1.035; $p < 0.001$), preoperative PT (cOR, 1.040; $p = 0.015$), preoperative SS (cOR, 0.964; $p = 0.020$), preoperative suboptimal SVA (cOR, 4.017; $p = 0.003$), postoperative LL (cOR, 0.965; $p = 0.014$), postoperative PI–LL mismatch (cOR, 1.034; $p = 0.017$), and postoperative PT (cOR, 1.047; $p = 0.038$) (Table 4). Multivariate analysis using a stepwise method identified that the number of spinal levels fused ≥ 4 ($p < 0.001$), preoperative BMD (aOR, 0.667; $p = 0.035$), and postoperative PI–LL mismatch (aOR, 1.034; $p = 0.040$) were significant risk factors for nonunion of the L5–S1 interbody fusion (Table 5).

DISCUSSION

The LS junction is known to exhibit higher nonunion rates than other lumbar segments, especially in long-segment fusion.[9,19] Nonunion at the LS junction is associated with increased low back pain, spinal imbalance, metal failure, and poor surgical outcomes.[2] By evaluating fusion status using CT in patients with instrumented LS fusion from the sacrum without SPF, we found that fusion to or above L2 had significantly lower L5–S1 interbody fusion rates than those below L2.

There have been controversies regarding definite indications for additional stronger fixation depending on the fusion length from the sacrum between levels 3 and 4. In addition, it may also be affected by the patient's condition, bone quality, sagittal alignment, paraspinal muscle status, and surgeon preferences. In the current review of 175 patients, LS fusion extending to or above L2 was a significant risk factor for nonunion at L5–S1, which is consistent with several previous studies.[5,7] While there was a tendency toward decreased fusion rates as fusion length increased in our results, fusion rates abruptly dropped between fusion lengths of 3 and 4 levels (Fig. 4). However, we also recommend considering additional augmentation to achieve stronger fixation in patients with fusion extending cranial to L3, depending on the patient's condition, because 20% of those also had pseudarthrosis at L5–S1 in our cohort.

In the current study, the fusion status of the L5–S1 interbody fusion was assessed using CT ≥ 1 year postoperatively in all included patients. Previous studies that used plain radiography to evaluate fusion status generally depended on indirect findings, such as implant failure, deformity progression, and the presence of excessive motion, rather than the direct assessment of bone bridge formation.[5,9] However, CT would be more efficient in assessing interbody fusion status because it enables the direct detection of the continuity of osseous trabeculation in the disc space.[12,19] Therefore, our results are meaningful because they provide L5–S1 interbody fusion rates assessed by CT according to the number of levels fused.

Although poor bone quality has been reported to be associated with nonunion after spinal fusion surgery in several previous studies,[20,21] some authors have reported no correlation between bone quality and nonunion.[2,12,22] Our results revealed that BMD had a noticeable effect on the development of pseudarthrosis at L5–S1. It appears reasonable to assume that the underlying bone quality of patients has a considerable effect on bone formation

and stability after instrumented fusion surgery. While several previous studies reporting no correlation between bone quality and nonunion included BMD scores of only some portion of the included patients or the presence of osteoporosis as a presumed risk factor,[5,12,22] our study collected BMD scores for all included patients. Therefore, we recommend meticulous surgical techniques and careful perioperative planning, such as additional SPF, restoration of optimal alignment, careful selection of implants and bone graft biological agents, and consideration of the perioperative use of bone-forming agents for patients with low preoperative BMD scores.

Many studies have investigated the relationship between sagittal alignment and surgical outcomes, including fusion rates and functional outcomes, after lumbar fusion surgery.[2,23] Some authors have proposed that unsatisfactory reconstruction of sagittal balance is associated with pseudarthrosis and fixation failure after long construct fusions for adult spinal deformity.[4,9] Sagittal malalignment may induce an imbalance in mechanical forces, resulting in poor long-term surgical outcomes. Postoperative PI–LL mismatch was identified as an independent risk factor for nonunion of L5–S1 interbody fusion in this study, which is consistent with the literature. Although our study included not only long-level but also short-level fusion, postoperative sagittal alignment still had a significant impact on interbody fusion at L5–S1. Meanwhile, because whole spine radiography was not consistently performed at 4 weeks postoperatively in our retrospective cohort, analysis of postoperative SVA was not possible in our study despite its clinical significance. As such, a well-designed prospective study evaluating spinal alignment and L5–S1 interbody fusion rates in terms of fused levels is required for more clarity.

Spinal sarcopenia is associated with pain, spinal alignment, and subsequent quality of life.[24,25] Unlike previous studies evaluating nonunion at L5–S1, we included the quantified status of the paraspinal muscles as a presumed risk factor. Several studies evaluating paraspinal muscles reported that the CSA and fat infiltration at L3–4 were most similar to the mean values of the entire lumbar area.[18] Additionally, L3 was found to be the ideal level for CT-based sarcopenia evaluation.[26] Therefore, the degree of atrophy and fat infiltration of the paraspinal muscles was assessed quantitatively using MRI at the lower endplate of the L3 level in the current study. However, the paraspinal muscle status was not a significant risk factor for nonunion at L5–S1. As the LS junction is at the end of the working length of the entire muscle, the effects of volume and quality of the paraspinal muscles may not be significant compared to the considerable impact of a large cantilever effect in long-level fusion. A well-designed biomechanical study analyzing the association between paraspinal muscle status and interbody nonunion is warranted.

The present study has several limitations. First, owing to its retrospective nature, selection bias may have been introduced or some confounding factors may not have been considered. Second, our cohort was somewhat heterogenous because we included patients with various LDD, such as history of previous fusion surgery and adult spinal deformity. In addition, the number of patients with ≥ 3-level fusion was relatively small because we tended to perform IS or S2AIS fixation for long-segment fusion. Third, although we attempted to quantitatively evaluate the volume and quality of the paraspinal muscles according to previously reported methods, a more clinically relevant method may be required rather than using MRI. Finally, incomplete medical records or evaluations, such as consistent documentation of clinical outcomes and postoperative SVA, may have limited the interpretation of our results. Despite these limitations, to our knowledge, this study is the first to evaluate the fusion status of L5–S1 interbody fusion using CT based on the number of levels fused with various potential factors in patients with instrumented fusion from the sacrum without additional augmentation. Our findings may help spine surgeons determine whether to perform SPF in surgical planning for various LDD.

The number of levels fused ≥ 4, lower BMD, and larger postoperative PI–LL mismatch were identified as independent risk factors for nonunion of L5–S1 interbody fusion in patients with instrumented fusion from the sacrum. Therefore, SPF fixation, such as IS or S2AIS fixation, is required for LS fusion extending to or above L2 and poor bone quality. In addition, meticulous preoperative planning and consideration of SPF are recommended even for < 4-level fusion in patients with vulnerable factors for nonunion because a few patients exhibited nonunion of L5–S1 interbody fusion.

CONFLICT OF INTEREST

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

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