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Comparative analysis of 3 surgical strategies for adult spinal deformity with mild to moderate sagittal imbalance

Junseok Bae, MD,[1] Alexander A. Theologis, MD,[2] Russell Strom, MD,[2] Bobby Tay, MD,[2] Shane Burch, MD,[2] Sigurd Berven, MD,[2] Praveen V. Mummaneni, MD,[3] Dean Chou, MD,[3] Christopher P. Ames, MD,[3] and Vedat Deviren, MD[2]

[1]Department of Neurological Surgery, Wooridul Spine Hospital, Seoul, South Korea; and Departments of [2]Orthopaedic Surgery and [3]Neurological Surgery, University of California, San Francisco, California

OBJECTIVE Surgical treatment of adult spinal deformity (ASD) is an effective endeavor that can be accomplished using a variety of surgical strategies. Here, the authors assess and compare radiographic data, complications, and health-related quality-of-life (HRQoL) outcome scores among patients with ASD who underwent a posterior spinal fixation (PSF)–only approach, a posterior approach combined with lateral lumbar interbody fusion (LLIF+PSF), or a posterior approach combined with anterior lumbar interbody fusion (ALIF+PSF).

METHODS The medical records of consecutive adults who underwent thoracolumbar fusion for ASD between 2003 and 2013 at a single institution were reviewed. Included were patients who underwent instrumentation from the pelvis to L-1 or above, had a sagittal vertical axis (SVA) of < 10 cm, and underwent a minimum of 2 years' follow-up. Those who underwent a 3-column osteotomy were excluded. Three groups of patients were compared on the basis of the procedure performed, LLIF+PSF, ALIF+PSF, and PSF only. Perioperative spinal deformity parameters, complications, and HRQoL outcome scores (Oswestry Disability Index [ODI], Scoliosis Research Society 22-question Questionnaire [SRS-22], 36-Item Short Form Health Survey [SF-36], visual analog scale [VAS] for back/leg pain) from each group were assessed and compared with each other using ANOVA. The minimal clinically important differences used were −1.2 (VAS back pain), −1.6 (VAS leg pain), −15 (ODI), 0.587/0.375/0.8/0.42 (SRS-22 pain/function/self-image/mental health), and 5.2 (SF-36, physical component summary).

RESULTS A total of 221 patients (58 LLIF, 91 ALIF, 72 PSF only) met the inclusion criteria. Average deformities consisted of a SVA of < 10 cm, a pelvic incidence–lumbar lordosis (LL) mismatch of > 10°, a pelvic tilt of > 20°, a lumbar Cobb angle of > 20°, and a thoracic Cobb angle of > 15°. Preoperative SVA, LL, pelvic incidence–LL mismatch, and lumbar and thoracic Cobb angles were similar among the groups. Patients in the PSF-only group had more comorbidities, those in the ALIF+PSF group were, on average, younger and had a lower body mass index than those in the LLIF+PSF group, and patients in the LLIF+PSF group had a significantly higher mean number of interbody fusion levels than those in the ALIF+PSF and PSF-only groups. At final follow-up, all radiographic parameters and the mean numbers of complications were similar among the groups. Patients in the LLIF+PSF group had proximal junctional kyphosis that required revision surgery significantly less often and fewer proximal junctional fractures and vertebral slips. All preoperative HRQoL scores were similar among the groups. After surgery, the LLIF+PSF group had a significantly lower ODI score, higher SRS-22 self-image/total scores, and greater achievement of the minimal clinically important difference for the SRS-22 pain score.

CONCLUSIONS Satisfactory radiographic outcomes can be achieved similarly and adequately with these 3 surgical approaches for patients with ASD with mild to moderate sagittal deformity. Compared with patients treated with an ALIF+PSF or PSF-only surgical strategy, patients who underwent LLIF+PSF had lower rates of proximal junctional ky-

ABBREVIATIONS ALIF = anterior LIF; ASD = adult spinal deformity; BMI = body mass index; HRQoL = health-related quality of life; LIF = lumbar interbody fusion; LL = lumbar lordosis; LLIF = lateral LIF; MCID = minimal clinically important difference; MCS = mental component summary; ODI = Oswestry Disability Index; PCS = physical component summary; PI = pelvic incidence; PJA = proximal junctional angle; PJK = proximal junctional kyphosis; PLIF = posterior LIF; PSF = posterior spinal fixation; PT = pelvic tilt; SF-36 = 36-Item Short Form Health Survey; SRS-22 = Scoliosis Research Society 22-question Questionnaire; SVA = sagittal vertical axis; TLIF = transforaminal LIF; UIV = upper instrumented vertebra; VAS = visual analog scale.

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phosis and mechanical failure at the upper instrumented vertebra and less back pain, less disability, and better SRS-22 scores.

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KEY WORDS adult spinal deformity; hybrid surgery; sagittal imbalance; lateral lumbar interbody fusion; anterior lumbar interbody fusion

Treatment options for adult spinal deformity (ASD) are varied according to the patient's baseline condition. Patients with minimal pain and mild thoracolumbar coronal deformity might benefit from conservative treatment.[18] The goal of surgical treatment for patients with ASD is to achieve sagittal and coronal balance, relieve axial and radiating pain, and achieve fusion. The surgical treatment of ASD is an effective endeavor that can be accomplished using a variety of surgical strategies. Interbody fusion has been advocated as an important surgical option in the treatment of ASD, because it can increase intervertebral disc height, provide indirect decompression of the neural foramen, enable circumferential fusion, and increase lumbar lordosis (LL).[1,2,21] Lumbar interbody fusion (LIF) can be achieved via multiple approaches, including the posterior (PLIF), transforaminal (TLIF), lateral (LLIF), and anterior (ALIF) LIF approaches.

Although the surgical plan for achieving satisfactory balance depends on the type of deformity, the patient's condition, and the surgeon's experience, 3-column osteotomy is often required for decompensated rigid deformity with severe sagittal imbalance. For patients with ASD and mild to moderate global sagittal imbalance (sagittal vertical axis [SVA] less than 10 cm),[26] surgical strategies are widely varied according to surgeon preference for interbody fusion, adaptation of minimally invasive surgical technique, and type of deformity.[14,23,27]

In an attempt to decrease blood loss, minimize soft-tissue dissection, and improve recovery times after ASD operations, minimally invasive surgical approaches have gained popularity in this arena. Although concerns have been raised regarding the ability of these approaches to correct sagittal plane deformity, the evolution of instrumentation for minimally invasive surgeries has broadened their applicability.[10,20,29]

To evaluate the effectiveness of different surgical strategies in the treatment of ASD with mild to moderate sagittal imbalance, we assessed and compared radiographic data, complications, and health-related quality-of-life (HRQoL) outcome scores among patients with ASD who underwent surgery performed using 1 of 3 different techniques, a posterior spinal fixation (PSF)–only approach, a posterior approach combined with LLIF (LLIF+PSF), or a posterior approach combined with ALIF (ALIF+PSF).

Methods

Patient Population

The medical records of consecutive adults (aged > 18 years) who underwent surgery for ASD at a single institution between 2003 and 2013 were reviewed retrospectively. Included were patients who underwent posterior instrumentation from the pelvis to L-1 or above and had mild to moderate sagittal imbalance (SVA < 10 cm), a minimum of 2 years' follow-up, and at least 1 of the following measurements of spinal deformity: coronal Cobb angle > 20°, pelvic tilt (PT) > 20°, and pelvic incidence (PI)–LL mismatch > 10°. Patients with severe sagittal imbalance (SVA > 10 cm) and those who underwent 3-column osteotomy, had a spinal deformity related to infection, or had malignant disease were excluded. Patients were categorized into 1 of 3 groups according to the surgical strategy implemented: LLIF+PSF, ALIF+PSF, or PSF only (Fig. 1). The LLIF+PSF group included patients who underwent TLIF at the L5–S1 level.

Surgical Procedures

We used no specific criteria for selecting one approach over another. Three approaches were used throughout the study period; LLIF was introduced later than the others. In general, the pairs of surgeries (in the LLIF+PSF and ALIF+PSF groups) were performed separately so that the remaining correction needed could be gauged. In the first stage, multilevel LLIF or ALIF was performed. For LLIF, the concave side was approached to maximize the number of interbody grafts and to restore foraminal height for indirect decompression in the coronal deformities. After docking on the lateral annulus and placing a tubular retractor via the transpsoas approach, discectomy and release of the far side of the annulus was performed, followed by implantation of the polyetheretherketone cage, which included cellular allograft. TLIF was performed at the L5–S1 level during the subsequent posterior approach. For ALIF, the patient was placed in the supine position. After fluoroscopic identification of the index level, a midline skin incision was made. A retroperitoneal approach to the appropriate disc space was achieved using a self-retaining retractor. After careful dissection and retraction of the abdominal vessels, the anterior longitudinal ligament, disc material, and posterior annulus were removed. A polyetheretherketone cage filled with cellular allograft was inserted. A plate was placed over the anterior vertebral body to protect against cage migration. For the posterior approach, the patient was placed on a Jackson table. After a midline skin incision and muscle dissection, interspinous ligament resection and multilevel Schwab Grade 1 or 2 osteotomies[25] was performed. Segmental pedicle screws and iliac bolts were placed routinely. LL was restored using a rod cantilever and compression technique. Local autograft, iliac crest autograft, and corticocancellous chips were applied together with bone morphogenetic protein for fusion. For the PSF-only approach, a surgical procedure for ligament resection and osteotomies similar to that described for the posterior approach after ALIF or LLIF was performed in addition to multilevel TLIF in a single stage.

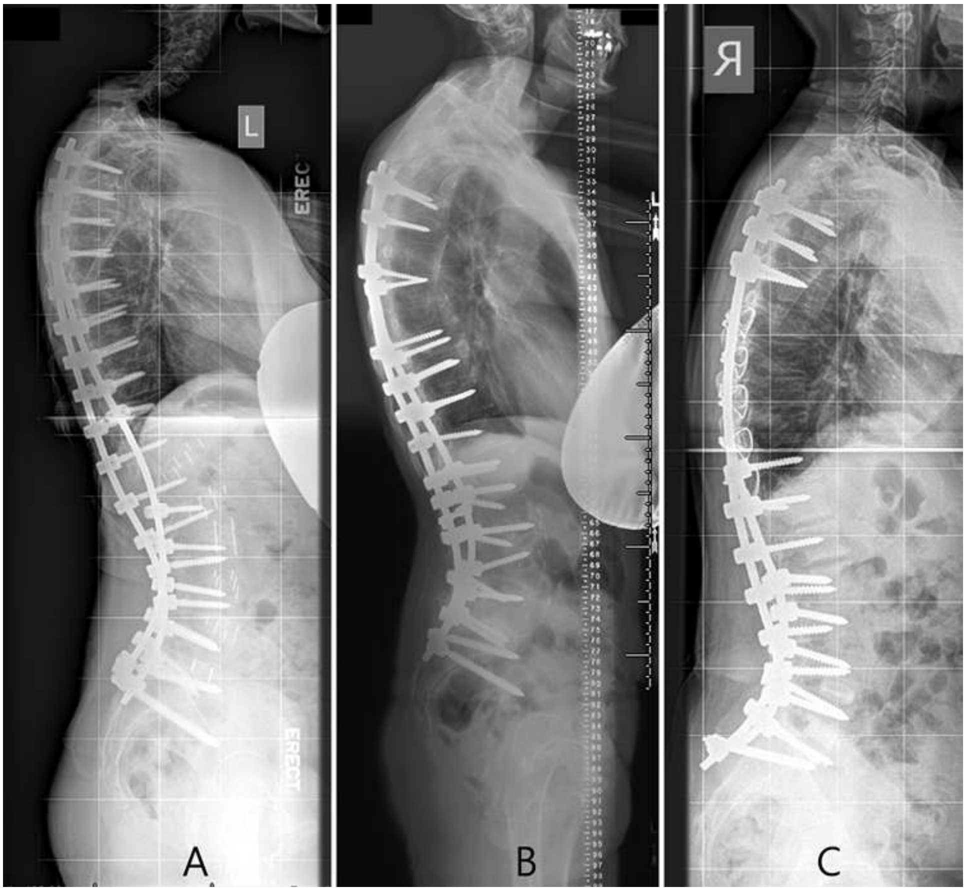

FIG. 1. Lateral standing radiographs of patients after surgery. **A:** LLIF+PSF. **B:** ALIF+PSF. **C:** PSF only.

Clinical Data, Radiological Assessment, and HRQoL Scores

Demographic and clinical data included patient age, sex, body mass index (BMI), smoking status, comorbidities, location of upper instrumented vertebra (UIV) (upper thoracic [T1–T7] and lower thoracic [T8–L1]), number of interbody fusion and posterior levels, incidence of proximal junctional kyphosis (PJK), mechanism of PJK (screw pullout, fracture, or spondylolisthesis), revision surgery, pseudarthrosis, and other complications.

Full-length standing anteroposterior and lateral radiographs were analyzed on Surgimap software (Nemaris) at 3 time points—baseline, 6 weeks after surgery, and final follow-up. Radiographic spinal deformity parameter measurements included C7–S1 SVA (plumb line from the center of the C-7 vertebral body to the posterior sacral prominence on the lateral radiograph), thoracic kyphosis (sagittal Cobb angle from the superior endplate of T-5 to the inferior endplate of T-12), LL (sagittal Cobb angle of the inferior endplate of T-12 to the superior endplate of S-1), PI (angle between a line perpendicular to the superior endplate of S-1 and the line connecting the superior endplate of S-1 to the bicoxofemoral axis), sacral slope (angle between the superior endplate of S-1 and the horizontal line), PT (angle made between lines originating at the bicoxofemoral axis and extending vertically and to the middle of the superior endplate of S-1), PI-LL mismatch, proximal junctional angle (PJA) (sagittal Cobb angle between the UIV and the UIV plus 2 levels [UIV+2]), coronal Cobb angle of thoracic and lumbar curves, and coronal imbalance.

Standardized HRQoL measures included a visual analog scale (VAS) for back pain and leg pain (0 no pain, 10 most severe pain), the Oswestry Disability Index (ODI), the 36-Item Short Form Health Survey (SF-36), and the Scoliosis Research Society 22-question Questionnaire (SRS-22). Two standard summary scores, the physical component summary (PCS) and the mental component summary (MCS), were based on the SF-36.[30] The SRS-22 provided a total score and scores on 5 subdomains, including pain, function, self-image, mental health, and satisfaction. To place HRQoL outcomes in a clinically relevant context, values for minimal clinically important differences (MCIDs) have been established. In this study, MCIDs were defined as the following according to previous reports[5,7,8,11,24]: −1.2 VAS back pain score, −1.6 VAS leg pain score, −15 ODI, 0.587/0.375/0.8/0.42 SRS-22 pain/function/self-image/mental health subdomain scores, and 5.2 SF-36 PCS score. Analyses of the differences in the proportions of patients whose HRQoL measures reached an MCID were performed.

Statistical Analyses

Continuous variables are presented as means ± SD. Frequency analysis was used for categorical variables.

TABLE 1. Demographic data

Demographic	All Patients	Group LLIF+PSF	ALIF+PSF	PSF-Only	p Value
No. of patients	221	58	91	72	
Age in yrs (mean ± SD)	64.2 ± 8.9	64.9 ± 7.8	62.6 ± 8.5	65.7 ± 9.8	0.063
Sex (female/male)	186:35	46:12	76:15	64:8	0.323
BMI in kg/m^2 (mean ± SD)	27.3 ± 5.4	28.1 ± 5.7	26.1 ± 4.5	28.1 ± 5.5	0.026
Smoker (%)	39.1	29.8	42	42.8	0.527
No. of comorbidities (mean ± SD)	2.7 ± 1.8	2.4 ± 1.9	2.6 ± 1.6	3.2 ± 1.9	0.034
Follow-up in mos (mean ± SD)	34.5 ± 21.7	28.9 ± 19.5	36.3 ± 21.8	36.8 ± 22.6	0.072
UIV (%)					0.715
Upper thoracic (T1–7)	28.1	27.6	30.8	25.0	
Lower thoracic (T8–L1)	71.9	72.4	69.2	75.0	
Interbody fusion performed (%)	72.9	100	100	16.7	0.000
No. of interbody fusion levels (mean ± SD)	3.3 ± 1.2	3.8 ± 1.2	2.7 ± 0.8	0.5 ± 0.7	0.000
No. of posterior fusion levels (mean ± SD)	6.5 ± 4.4	4.0 ± 3.3	7.1 ± 4.8	8.1 ± 2.9	0.077
SVA (%)					0.602
≤5 cm	65	62.1	68.9	62.5	
>5 but <10 cm	35	37.9	31.1	37.5	
PI-LL mismatch (%)					0.534
≤10°	41.6	37.9	41.2	45.1	
>10° but <20°	27.1	24.1	25.9	31.0	
>20°	31.3	37.9	32.9	23.9	
PT (%)					0.752
≤20°	36.9	40.4	36.0	35.2	
>20° but <30°	44.9	47.4	44.2	43.7	
≥30°	18.2	12.3	19.8	21.1	

ANOVA and the Kruskal-Wallis test were used as appropriate for group comparisons. A p value < 0.05 defined statistical significance. All analyses were performed using SPSS 14.0 K (SPSS, Inc.).

Results

Two hundred twenty-one patients met the inclusion criteria. The cohort included 186 women and 35 men, and their mean age was 64 ± 9 years; the mean follow-up period was 34.5 ± 21.7 months. Fifty-eight patients underwent LLIF+PSF, 91 underwent ALIF+PSF, and 72 underwent PSF only. Preoperative SVA, LL, PI-LL mismatch, and lumbar and thoracic Cobb angles were similar among the 3 groups. Patients who underwent PSF only had more comorbidities. Patients who underwent ALIF+PSF were, on average, younger than those who underwent LLIF+PSF (62.6 vs 64.9 years, respectively) and had a lower BMI (26.1 vs 28.1 kg/m^2, respectively). The LLIF+PSF group had a significantly higher mean number of interbody fusion levels (3.8 ± 1.2 levels) than the ALIF+PSF and PSF-only groups (2.7 ± 0.8 and 0.5 ± 0.7 levels, respectively). In terms of the date of surgery, patients in the ALIF+PSF and PSF-only groups underwent surgery, on average, 1 year later than those in the LLIF+PSF group, but the follow-up period did not differ among the 3 groups. Additional demographic data are presented in Table 1.

At final follow-up, all radiographic parameters were similar among the 3 groups (Table 2). The PJA between UIV and UIV+2 was highest in the PSF-only group (17.9° ± 12.9° vs 15.0° ± 10.9° [ALIF+PSF group] and 13.1° ± 9.8° [LLIF+PSF group]; p = 0.051). The percent change between the preoperative and final follow-up PJA was significantly lower in the LLIF+PSF group than in the other groups (148.3% ± 300.6% vs 258.1% ± 449.1% [ALIF+PSF] and 356.2% ± 575.3% [PSF-only group]; p = 0.047). The average numbers of complications were similar among the 3 groups. Compared with patients who underwent ALIF+PSF and PSF only, those who underwent LLIF+PSF had significantly fewer PJKs (41.8% vs 38.9% vs 22.4%, respectively), fewer UIV fractures (28.6% vs 31.9% vs 13.8%, respectively), and fewer UIV spondylolistheses (5.5% vs 6.9% vs 0%, respectively). Revision rates and the numbers of pseudarthrosis, hardware prominence, and other perioperative complications were similar among the 3 groups (Table 3).

Table 4 shows comparisons of preoperative and postoperative HRQoL data. All preoperative HRQoL scores were similar among the 3 groups. After surgery, patients in the LLIF+PSF group had a significantly lower ODI, higher SRS-22 self-image/total scores, and greater percent improvement in the total SRS-22 score. Patients in the LLIF+PSF group had greater achievement of the MCID in the SRS-22 pain score than those in the ALIF+PSF and PSF-only groups (88.9% vs 60.4% vs 42.3%, respectively; p = 0.002) (Table 5).

TABLE 2. Sagittal and coronal radiographic data

Radiographic Data	All Patients	Group			p Value
		LLIF+PSF	ALIF+PSF	PSF-Only	
SVA (mm)					
Preop	36.5 ± 33.9	39.2 ± 36.4	32.2 ± 32.5	39.8 ± 33.4	0.287
First postop	25.3 ± 45.5	22.3 ± 46.6	24.6 ± 46.2	28.4 ± 43.9	0.74
Final postop	32.3 ± 45.3	26.2 ± 51.2	30.1 ± 46.7	39.9 ± 37.5	0.189
(Final-pre)/pre (%)	−44 ± 772	−99.8 ± 755.8	55.7 ± 658.8	−126 ± 903	0.27
p value (pre-final)	0.166	0.046	0.65	0.969	
Thoracic kyphosis (°)					
Preop	33.5 ± 16.5	33.1 ± 14.8	31.5 ± 17.6	36.3 ± 15.7	0.182
First postop	39.5 ± 15.1	36.8 ± 12.4	39.7 ± 16.5	41.3 ± 15.1	0.248
Final postop	42.6 ± 16.5	40.6 ± 13.8	42.5 ± 17.9	44.4 ± 16.4	0.449
(Final-pre)/pre (%)	58.2 ± 169.6	40.6 ± 91.5	69.9 ± 148.9	57.2 ± 231.6	0.594
p value (pre-final)	<0.001	<0.001	<0.001	<0.001	
LL (°)					
Preop	40.0 ± 15.9	39.1 ± 13.9	40.4 ± 18.1	40.3 ± 14.5	0.865
First postop	49.2 ± 13.9	51.8 ± 12.3	49.5 ± 14.8	46.6 ± 13.8	0.108
Final postop	48.4 ± 13.8	50.3 ± 12.3	48.8 ± 15.1	46.1 ± 12.9	0.225
(Final-pre)/pre (%)	46.7 ± 131.6	44.9 ± 84.2	58.5 ± 160.1	33.5 ± 123.5	0.484
p value (pre-final)	<0.001	<0.001	<0.001	<0.001	
PI-LL mismatch (°)					
Preop	12.2 ± 15.7	14.3 ± 15.1	11.4 ± 17.3	11.3 ± 14.2	0.482
First postop	3.7 ± 14.3	2.3 ± 13.7	3.0 ± 14.5	5.5 ± 14.7	0.406
Final postop	4.6 ± 15.5	3.6 ± 16.9	3.2 ± 14.7	6.9 ± 14.9	0.262
(Final-pre)/pre (%)	−58.2 ± 269.6	−91.8 ± 293.3	−54.3 ± 306.6	−36.9 ± 191.6	0.528
p value (pre-final)	<0.001	<0.001	<0.001	0.038	
PJA (UIV–UIV+2) (°)					
Preop	6.8 ± 6.4	5.5 ± 5.2	7.2 ± 6.3	7.6 ± 7.1	0.147
First postop	10.3 ± 9.1	9.0 ± 6.3	9.8 ± 9.9	11.8 ± 9.6	0.2
Final postop	15.5 ± 11.3	13.1 ± 9.8	15.0 ± 10.9	17.9 ± 12.9	**0.051**
(Final-pre)/pre (%)	260.6 ± 467.1	148.3 ± 300.6	258.1 ± 449.1	356.2 ± 575.3	**0.047**
p value (pre-final)	<0.001	<0.001	<0.001	<0.001	
PT (°)					
Preop	21.9 ± 10.6	21.1 ± 9.5	22.4 ± 11.6	21.8 ± 10.2	0.787
First postop	18.2 ± 9.9	16.7 ± 7.9	17.4 ± 10.4	20.5 ± 10.2	0.053
Final postop	20.8 ± 9.0	20.0 ± 7.5	20.3 ± 9.8	22.0 ± 9.1	0.374
(Final-pre)/pre (%)	9.7 ± 135.6	−7.8 ± 100.4	6.7 ± 99.9	27.3 ± 187.7	0.339
p value (pre-final)	0.058	0.117	0.08	0.907	
PI (°)					
Preop	52.5 ± 11.7	53.3 ± 9.9	52.6 ± 12.6	51.8 ± 12.2	0.755
First postop	53.0 ± 11.6	54.2 ± 9.3	52.7 ± 12.2	52.4 ± 12.5	0.659
Final postop	53.1 ± 11.6	54.0 ± 10.1	54.6 ± 12.3	52.7 ± 11.9	0.768
(Final-pre)/pre (%)	−1.1 ± 14.5	−0.8 ± 13.9	−1.1 ± 12.2	−1.4 ± 17.4	0.963
p value (pre-final)	0.066	0.118	0.872	0.230	
Sacral slope (°)					
Preop	30.5 ± 10.6	31.3 ± 10.7	30.1 ± 10.5	30.2 ± 10.5	0.765
First postop	34.5 ± 10.5	36.5 ± 9.1	35.4 ± 10.6	31.9 ± 11.1	0.025
Final postop	31.9 ± 9.8	33.3 ± 8.4	32.0 ± 10.2	30.8 ± 10.3	0.365
(Final-pre)/pre (%)	15.1 ± 108.2	13.3 ± 41.2	25.5 ± 161.4	3.7 ± 47.1	0.455
p value (pre-final)	0.024	0.046	0.135	0.712	

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TABLE 2. Sagittal and coronal radiographic data

Radiographic Data	All Patients	Group			p Value
		LLIF+PSF	ALIF+PSF	PSF-Only	
Thoracic Cobb angle (°)					
Preop	17.9 ± 14.8	16.5 ± 15.2	18.7 ± 14.2	18.2 ± 15.5	0.655
First postop	9.9 ± 9.9	8.6 ± 9.2	10.7 ± 10.3	10.1 ± 10.1	0.457
Final postop	10.5 ± 9.8	8.9 ± 10.1	11.2 ± 10.0	10.8 ± 9.2	0.379
(Final-pre)/pre (%)	−6.7 ± 160.8	5.9 ± 263.8	−11.9 ± 115.5	−10.3 ± 88.7	0.792
p value (pre-final)	<0.001	<0.001	<0.001	<0.001	
Lumbar Cobb angle (°)					
Preop	28.7 ± 17.3	30.0 ± 19.1	30.7 ± 16.5	25.0 ± 16.1	0.085
First postop	14.3 ± 11.2	13.0 ± 11.0	15.2 ± 11.1	14.2 ± 11.7	0.509
Final postop	14.9 ± 11.3	14.2 ± 12.5	15.8 ± 11.6	14.2 ± 9.8	0.559
(Final-pre)/pre (%)	−35.5 ± 68.1	−42.7 ± 70.8	−38.5 ± 50.2	−25.7 ± 83.8	0.324
p value (pre-final)	<0.001	<0.001	<0.001	<0.001	
Coronal imbalance (mm)					
Preop	10.1 ± 30.7	7.6 ± 39.6	12.7 ± 25.4	8.8 ± 28.5	0.555
First postop	8.6 ± 24.6	10.3 ± 24.7	11.1 ± 21.9	3.8 ± 27.3	0.150
Final postop	7.2 ± 25.4	10.7 ± 25.2	9.1 ± 25.5	1.9 ± 24.8	0.098
(Final-pre)/pre (%)	−29.6 ± 301.8	−40.4 ± 351.1	−10.6 ± 318.6	−44.3 ± 235.1	0.753
p value (pre-final)	0.174	0.606	0.201	0.051	

(Final-pre)/pre = percent difference calculated by (final postoperative value − preoperative value)/preoperative value; p value (pre-final) = p value of paired t-test between the preoperative value and the final postoperative value.
Values are means ± SD. Boldface type indicates statistical significance.

TABLE 3. Summary of complications

Complication	All Patients	Group			p Value
		LLIF+PSF	ALIF+PSF	PSF-Only	
PJK (%)	35.7	22.4	41.8	38.9	**0.045**
PJK mechanism (%)					
Screw pullout	14	15.5	15.4	11.1	0.687
UIV fracture	25.8	13.8	28.6	31.9	**0.047**
Spondylolisthesis	4.5	0.0	5.5	6.9	0.142
Revision due to PJK (%)	12.7	8.6	13.2	15.3	0.517
Revision due to non-PJK (%)	25.3	24.1	18.7	34.7	0.064
Pseudarthrosis (%)	10.9	8.6	8.8	15.3	0.342
Hardware prominence, failure (%)	8.1	6.9	5.5	12.5	0.248
Complications (%)					
Implant	4.5	3.4	4.4	5.6	0.846
Infection	18.6	15.5	20.9	18.1	0.709
Neurological	8.2	10.3	7.7	7.0	0.775
Cardiopulmonary	14.5	17.2	17.6	8.3	0.197
Vascular	1.4	3.4	1.1	0.0	0.233
Gastrointestinal	10.0	6.9	9.9	12.5	0.571
Renal	4.5	8.6	3.3	2.8	0.216
Anemia	57.7	55.2	65.6	50.0	0.125
Operative	4.1	5.2	5.5	1.4	0.374
Total complications (mean ± SD)	1.5 ± 1.1	1.6 ± 1.1	1.6 ± 1.2	1.3 ± 0.9	0.082

Boldface type indicates statistical significance.

TABLE 4. Summary of HRQoL measures

HRQoL Measure	Total	Group			p Value
		LLIF+PSF	ALIF+PSF	PSF-Only	
VAS back score					
Preop	6.2 ± 2.7	6.3 ± 2.9	6.3 ± 2.6	5.9 ± 3.1	0.761
First postop	3.4 ± 2.7	3.4 ± 2.3	3.5 ± 2.9	3.4 ± 2.9	0.989
Final postop	3.3 ± 2.9	3.2 ± 2.9	3.1 ± 2.9	3.8 ± 3.2	0.398
(Final-pre)/pre (%)	−46.4 ± 54.5	−57.3 ± 37.6	−45.3 ± 63.9	−36.3 ± 48.6	0.361
p value (pre-final)	<0.001	<0.001	<0.001	0.011	
VAS leg score					
Preop	3.9 ± 3.6	4.8 ± 3.6	3.5 ± 3.5	3.7 ± 3.7	0.215
First postop	1.6 ± 2.4	2.1 ± 2.5	1.2 ± 2.0	1.9 ± 2.9	0.294
Final postop	2.1 ± 2.8	2.1 ± 2.9	2.2 ± 2.7	1.9 ± 2.8	0.924
(Final-pre)/pre (%)	−60.8 ± 49.5	−61.4 ± 47.2	−61.5 ± 55.2	−58.7 ± 41.4	0.981
p value (pre-final)	<0.001	<0.001	0.006	0.004	
ODI					
Preop	46.1 ± 14.5	47.2 ± 15.1	45.3 ± 14.8	46.2 ± 13.5	0.834
First postop	50.3 ± 15.9	50.0 ± 18.1	49.6 ± 15.0	51.9 ± 15.2	0.35
Final postop	34.3 ± 17.9	30.2 ± 16.0	33.2 ± 18.5	39.2 ± 17.7	**0.058**
(Final-pre)/pre (%)	−26.6 ± 39.0	−38.2 ± 25.9	−26.1 ± 43.8	−15.7 ± 39.8	0.065
p value (pre-final)	<0.001	<0.001	<0.001	0.011	
SRS-22, function score					
Preop	2.8 ± 0.6	2.8 ± 0.7	2.8 ± 0.6	2.8 ± 0.5	0.748
First postop	2.8 ± 0.5	2.8 ± 0.5	2.8 ± 0.4	2.8 ± 0.5	0.855
Final postop	3.3 ± 0.6	3.5 ± 0.5	3.2 ± 0.7	3.2 ± 0.7	0.082
(Final-pre)/pre (%)	26.3 ± 24.2	35.6 ± 35.8	25.1 ± 38.0	21.3 ± 24.2	0.287
p value (pre-final)	<0.001	<0.001	<0.001	<0.001	
SRS-22, pain score					
Preop	2.4 ± 0.6	2.3 ± 0.7	2.5 ± 0.6	2.4 ± 0.7	0.496
First postop	2.5 ± 0.6	2.5 ± 0.8	2.5 ± 0.5	2.5 ± 0.7	0.974
Final postop	3.0 ± 0.9	3.2 ± 0.9	3.0 ± 0.8	2.8 ± 0.8	0.162
(Final-pre)/pre (%)	39.2 ± 47.3	60.1 ± 53.5	32.7 ± 38.7	29.5 ± 49.9	0.025
p value (pre-final)	<0.001	<0.001	<0.001	0.005	
SRS-22, self-image score					
Preop	2.7 ± 0.6	2.7 ± 0.7	2.6 ± 0.6	2.9 ± 0.7	0.08
First postop	3.6 ± 0.5	3.5 ± 0.5	3.6 ± 0.5	3.6 ± 0.6	0.894
Final postop	3.5 ± 0.7	3.7 ± 0.6	3.4 ± 0.8	3.3 ± 0.7	**0.043**
(Final-pre)/pre (%)	41.3 ± 46.3	49.5 ± 44.9	43.5 ± 48.1	28.7 ± 42.9	0.236
p value (pre-final)	<0.001	<0.001	<0.001	0.001	
SRS-22, mental health score					
Preop	3.6 ± 0.9	3.6 ± 0.9	3.6 ± 0.9	3.6 ± 0.8	0.998
First postop	3.8 ± 0.7	3.6 ± 0.8	3.9 ± 0.7	3.7 ± 0.8	0.209
Final postop	3.8 ± 0.8	3.8 ± 0.8	3.8 ± 0.9	3.8 ± 0.8	0.95
(Final-pre)/pre (%)	15.3 ± 35.7	15.9 ± 28.8	14.8 ± 38.3	15.8 ± 38.3	0.988
p value (pre-final)	0.01	0.023	0.043	0.079	
SRS-22, subtotal score					
Preop	2.9 ± 0.5	2.8 ± 0.5	2.8 ± 0.5	2.9 ± 0.4	0.389
First postop	3.1 ± 0.4	2.9 ± 0.4	3.2 ± 0.4	3.2 ± 0.5	0.105
Final postop	3.4 ± 0.6	3.6 ± 0.5	3.3 ± 0.6	3.3 ± 0.6	0.119
(Final-pre)/pre (%)	25.9 ± 26.9	36.6 ± 24.8	24.6 ± 27.7	18.7 ± 25.5	0.061
p value (pre-final)	<0.001	<0.001	<0.001	0.001	

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TABLE 4. Summary of HRQoL measures

HRQoL Measure	Total	Group			p Value
		LLIF+PSF	ALIF+PSF	PSF-Only	
SRS-22, satisfaction score					
Preop	2.9 ± 0.9	2.9 ± 0.9	2.9 ± 0.9	2.7 ± 0.8	0.532
First postop	4.0 ± 0.7	3.9 ± 0.7	4.1 ± 0.6	4.1 ± 0.6	0.712
Final postop	3.9 ± 0.8	4.1 ± 0.7	3.9 ± 0.9	3.8 ± 0.8	0.358
(Final-pre)/pre (%)	50.1 ± 62.3	57.3 ± 55.3	45.8 ± 65.4	50.1 ± 72.5	0.774
p value (pre-final)	<0.001	<0.001	<0.001	0.001	
SRS-22, total score					
Preop	2.9 ± 0.5	2.7 ± 0.6	2.8 ± 0.5	2.9 ± 0.4	0.545
First postop	3.4 ± 0.6	3.5 ± 0.8	3.3 ± 0.4	3.3 ± 0.5	0.43
Final postop	3.5 ± 0.7	3.8 ± 0.7	3.4 ± 0.6	3.3 ± 0.6	**0.003**
(Final-pre)/pre (%)	29.9 ± 33.1	46.3 ± 40.8	25.9 ± 28.6	20.3 ± 26.1	0.008
p value (pre-final)	<0.001	<0.001	<0.001	0.001	
SF-36/PCS score					
Preop	29.8 ± 8.5	28.1 ± 9.2	31.1 ± 8.4	29.1 ± 8.1	0.314
First postop	28.7 ± 7.3	29.5 ± 7.1	28.3 ± 7.2	28.2 ± 8.2	0.775
Final postop	34.7 ± 9.7	35.1 ± 9.7	35.8 ± 10.6	32.9 ± 8.7	0.292
(Final-pre)/pre (%)	24.2 ± 34.1	28.6 ± 37.0	25.1 ± 36.8	19.9 ± 27.8	0.629
p value (pre-final)	<0.001	0.003	<0.001	0.001	
SF-36/MCS score					
Preop	46.6 ± 13.4	44.2 ± 15.2	47.7 ± 13.7	46.7 ± 11.7	0.57
First postop	47.9 ± 12.9	46.5 ± 14.6	49.0 ± 12.1	47.5 ± 12.7	0.756
Final postop	48.8 ± 13.3	49.7 ± 13.3	49.1 ± 13.1	47.7 ± 13.7	0.769
(Final-pre)/pre (%)	18.4 ± 51.4	36.5 ± 73.3	11.5 ± 36.9	15.1 ± 48.9	0.138
p value (pre-final)	0.002	0.004	0.194	0.183	

Values are means ± SD. Boldface type indicates statistical significance.

Discussion

The ideal surgical treatment for ASD is a topic of much interest and debate. In this study, we assessed and compared radiographic data, complications, and HRQoL scores among patients with ASD and moderate sagittal deformity who underwent a PSF-only, LLIF+PSF, or ALIF+PSF. The major findings of our study are that satisfactory radiographic outcomes for patients with ASD can be achieved similarly and adequately with these 3 different surgical approaches and that patients who underwent LLIF+PSF experienced lower rates of PJK and mechanical failure at the UIV as well as less back pain, less disability, and better SRS-22 scores than those treated with the ALIF+PSF or PSF-only surgical strategy.

Posterior release, posterior interbody fusion, and reduction via a PSF-only approach have been shown to provide satisfactory multiplanar correction for adult scoliosis.[17] Although effective, the PSF-only approach has a higher reported rate of morbidity[3,6] and enables less access to the anterior vertebral body, which might compromise its ability to result in adequate spinal realignment and/or fusion. In addition, the posterior approach and placement of interbody cages via the posterior approach can be difficult when performing revision surgery in patients in whom significant scarring and bone grafting have altered the anatomy. The lower percentage of interbody fusion (16.7%) in the PSF-only group highlights this limitation of PSF-only approaches. As such, alternative approaches (i.e., anterior and lateral) offer unique advantages in the setting of ASD when combined with the posterior approach.

Both ALIF and LLIF are viable options for the treatment of ASD. ALIF offers several advantages over LLIF, including enabling direct decompression of neural foramina, providing accessibility to L5–S1, requiring less mobilization of the psoas muscle (which lowers the risk of lumbar plexus injury), and enabling resection of the anterior longitudinal ligament, wide discectomies, and insertion of wedge-shaped lordotic grafts. However, it does carry risks related to mobilization of the abdominal viscera and large vessels.[15,19,31] In contrast, LLIF can restore intervertebral disc height, which results in indirect decompression of neural foramina without jeopardizing segmental stability because it retains the anterior and posterior longitudinal ligaments.[1,4,9,12,16,21] Furthermore, wide interbody cages that support the lateral rims of the endplate can be placed via the lateral approach, which might translate into preventing subsidence and subsequent loss of deformity correction.

In our study, LLIF+PSF resulted in significantly fewer incidences of radiographic PJK than the ALIF+PSF and PSF-only approaches (22.4%, 41.8%, and 38.9%, respec-

TABLE 5. MCID achievement

HRQoL Measure	All Patients (%)	Group (%)			p Value
		LLIF+PSF	ALIF+PSF	PSF-Only	
VAS					
Back pain	60.7	71.9	62.5	44.8	0.092
Leg pain	47.0	50.0	46.4	44.8	0.916
ODI	45.8	57.6	44.2	36.4	0.217
SRS-22					
Pain	63.4	88.9	60.4	42.3	**0.002**
Function	63.4	74.1	60.4	57.7	0.395
Self-image	51.5	63.0	52.1	38.5	0.205
Mental health	42.6	44.4	41.7	42.3	0.973
SF-36/PCS	50.5	54.2	54.2	42.4	0.539

Boldface type indicates statistical significance.

tively), although the rates of revision performed because of PJK were not different among the 3 groups. The PSF-only group had a higher PJA at final follow-up than the hybrid groups and a higher incidence of fracture at the UIV. Patients in the PSF-only group also experienced a higher incidence of spondylolisthesis at the proximal junction (6.9% vs 0%, respectively), more revision surgeries (15.3% vs 8.6%, respectively), and more pseudarthroses (15.3% vs 8.6%, respectively) than those in the LLIF+PSF group (differences not statistically significant), which might explain why our LLIF+PSF group showed significant improvement in SRS-22 total and self-image scores over those of the ALIF+PSF and PSF-only groups; HRQoL scores are reportedly associated with improvement in radiographic alignment and negatively affected by complications that necessitate revision surgery.[22] Uribe et al.[28] reported that total complication rates were not different between their hybrid and open PSF-only groups (47% and 63%, respectively). We also found that complication rates were similar among our 3 groups. In addition, Hamilton et al.[13] compared reoperation rates in their hybrid (minimally invasive LLIF+PSF) and PSF-only groups and found that the rate of revision surgery was higher among patients in the hybrid group (27%) than those in the PSF-only group (12%). Interesting to note is that neurological deficit and PJK were the most common reasons for reoperation in the hybrid and PSF-only groups; the rates of revision surgery performed because of PJK were 9.5% in the hybrid group and 4.8% in the PSF-only group.[13] In contrast, our PSF-only group was found to have higher rates of revision surgery and incidence of radiographic PJK, but this difference was not significant in comparison with the other groups.

In addition, we found that all 3 surgical techniques (PSF only, ALIF+PSF, and LLIF+PSF) resulted in significant improvements in sagittal radiographic deformity parameters and HRQoL scores. Although Haque et al.[14] also found that LLIF+PSF resulted in greater restoration of PI-LL mismatch and SVA than did their PSF-only group, Hamilton et al.[13] found that the SVA was improved after surgery for patients in their PSF-only group but not for those in their LLIF+PSF group (53 mm [before surgery] vs 53.1 mm [after surgery]). These discrepancies highlight the heterogeneity of this disorder and the need for prospective studies to assess the efficacy of different surgical techniques among more homogeneous populations of people with ASD.

The findings of this study should be considered in the context of its limitations. One of its major limitations is its retrospective nature and that the choice of surgery was based mainly on surgeon preference. In addition, because the surgeries were performed by various surgeons over 10 years, it is difficult to differentiate between results of the different surgeries and the effects of individual differences and accumulation of experience among those surgeons. However, we found no difference between baseline deformity parameters, UIV, and postoperative deformity parameters, which represent the surgical goals, and achievements were constant even though the surgical strategies were different. Because the study included patients with various degrees of freedom in choosing their surgical procedure, it is difficult to extend the analysis to patients with severe deformity. Although this was a study of a large cohort from a single institution, it is necessary to confirm the results through a multicenter prospective study.

Conclusions

In adults with mild to moderate sagittal plane deformity, satisfactory radiographic outcomes can be achieved similarly and adequately with different surgical approaches. Compared with patients treated with an ALIF+PSF or PSF-only surgical strategy, patients who underwent LLIF+PSF had lower rates of PJK and mechanical failure at the UIV as well as less back pain, less disability, and better SRS-22 scores.

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Correspondence

Junseok Bae, Department of Neurological Surgery, Wooridul Spine Hospital, 445 Hakdong-ro, Gangnam-gu, Seoul 06068, South Korea. email: jsbaemd@gmail.com.