Long-term Outcomes After Adult Spinal Deformity Surgery Using Lateral Interbody Fusion

Short Versus Long Fusion

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Study Design: Retrospective cohort study.

Objective: To investigate long-term outcomes after short or long fusion for adult spinal deformity using lateral interbody fusion.

Summary of Background Data: Lateral interbody fusion is commonly used in adult spinal deformity surgery. Favorable short-term outcomes have been reported, but not long-term outcomes. Lateral interbody fusion with strong ability to correct deformity may allow the selection of short fusion techniques.

Materials and Methods: We retrospectively reviewed adults who underwent this surgery with a minimum of 5 years of follow-up. Short fusion with the uppermost instrumented vertebra in the lumbar spine was performed in patients without degenerative changes at the thoracolumbar junction (S-group); others underwent long fusion with the uppermost instrumented vertebra in the thoracic spine (L-group). We assessed radiographic and clinical outcomes.

Results: Short fusion was performed in 29 of 54 patients. One patient per group required revision surgery. Of the remainder, with similar preoperative characteristics and deformity correction between groups, correction loss (pelvic incidence-lumbar lordosis, $P=0.003$; pelvic tilt, $P=0.005$; sagittal vertical axis, $P<0.001$) occurred within 2 years postoperatively in the S-group, and sagittal vertical axis continued to increase until the 5-year follow-up ($P=0.021$). Although there was a significant change in Oswestry disability index in the S-group ($P=0.031$) and self-image of Scoliosis Research Society 22r score in both groups ($P=0.045$ and 0.02) from 2- to 5-year follow-up, minimum clinically important differences were not reached. At 5-year follow-up, there was a significant difference in Oswestry Disability Index ($P=0.013$) and Scoliosis Research Society 22r scores (function: $P=0.028$; pain: $P=0.003$; subtotal: $P=0.006$) between the groups, but satisfaction scores were comparable and Oswestry Disability Index score (29.8%) in the S-group indicated moderate disability.

Conclusions: Health-related quality of life was maintained between 2- and 5-year follow-up in both groups. Short fusion may be an option for patients without degenerative changes at the thoracolumbar junction.

Level of Evidence: III

Key Words: adult spinal deformity, lateral interbody fusion, long-term outcome, short fusion, long fusion

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The incidence of adult spinal deformity (ASD) is thought to be increasing in the aging population. Patients with ASD commonly have lower back pain, leg pain, and disabilities due to spinal malalignment in the sagittal and coronal planes.[1] Surgical treatment has been suggested by several studies to be superior to conservative treatment, especially for patients with severe ASD.[2,3] Traditionally, ASD has been managed with an open posterior-only approach, including high-volume osteotomy, but this is associated with greater blood loss, high morbidity, and high complication rates.[4,5] ASD mostly affects elderly people, so less invasive procedures have been of great interest. Lateral interbody fusion (LIF) has gained popularity as a less invasive technique for spinal diseases, including ASD, since the first description by Ozgur et al.[6] LIF, in conjunction with the posterior approach, has been shown to have a strong ability to correct deformity,[7,8] allowing surgeons to choose short fusion with the uppermost instrumented vertebra (UIV) in the lumber spine.[9] In addition to shorter operative time and less blood loss, short fusion has another advantage: reduction of stiffness-related functional disability after long fusion with the UIV in the thoracic spine.[10,11] To date, short-term or intermediate-term surgical outcomes of ASD surgery using LIF have been reported,[12–15] but not long-term outcomes. This study aims to investigate whether radiologic and clinical outcomes were maintained in the long term (2–5 years postoperatively) in both short and long fusion for ASD using LIF.

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MATERIALS AND METHODS

This retrospective study was conducted in compliance with the principles of the Declaration of Helsinki. The study protocol was reviewed and approved by our Institutional Review Board, and all study participants provided written informed consent. Patients with ASD who underwent corrective surgery were sorted from a single institutional database. ASD was defined as the presence of one of the following radiographic criteria: coronal Cobb angle > 20 degrees, C7-S1 sagittal vertical axis > 5 cm, or pelvic tilt > 25 degrees. Criteria for inclusion were age 50 years or above at the time of surgery, having lateral interbody fusion in the lumbar spine, and a minimum 5-year follow-up including radiographic and patient-reported outcome (PRO) measurements. Patients with spinal deformity with a syndromic etiology (eg, neuromuscular) were excluded from this study. In addition, patients with fixed sagittal imbalance and previous thoracic and/or lumbar spine surgery were excluded because they often require 3-column osteotomy.[16] The fusion level was decided based on our clinical experience and consideration of the patient's age, general health status, activity level, and radiographic examination results. Short fusion with the UIV in the lumbar spine was selected when patients had no degenerative changes of intervertebral disks and paraspinal muscles at the thoracolumbar junction preoperatively. In contrast, patients with the UIV in the lower thoracic spine (T9 or T10) were included in the long fusion group (L-group) in this study because those vertebrae were the most common UIV when long fusion was planned.[17,18] Ultimately, 54 patients were retrospectively reviewed. Posterior procedures after LIF included percutaneous pedicle screw fixation or open surgery with grade 1 or 2 osteotomy.[19]

The following radiographic parameters were measured via standing plain radiography preoperatively, immediately postoperatively, and at 2 and 5 years after surgery: PI (the angle between the line perpendicular to the sacral plate at its midpoint and the line connecting this point to the axis of the femoral heads), LL (the Cobb angle from the upper endplate of L1 to the upper endplate of S1), pelvic tilt (PT, the angle between the line connecting the midpoint of the sacral plate to the axis of the femoral heads and the vertical axis), sagittal vertical axis (SVA, the horizontal distance from the C7 plumb line originating at the middle of the C7 vertebral body to the posterior superior endplate of S1), and coronal balance (CB, the horizontal distance between the C7 plumb line originating at the middle of the C7 and the center of the sacrum on the coronal plane). As mechanical complications in radiographic assessment, we investigated proximal junctional kyphosis (PJK) and rod fracture (RF). PJK was defined using the following 2 criteria as in a previous study: a sagittal proximal junctional angle (from the lower plate of the UIV to the upper endplate of the vertebra 2 levels above the UIV) > 10 and ≥ 10 degrees of progression of a sagittal proximal junctional angle from the preoperative measurement.[20]

PRO measurements comprised the Scoliosis Research Society 22r (SRS-22r) and Oswestry Disability Index (ODI), both of which are frequently used and have been shown to be reliable and valid in the field of ASD.[21–24] PROs were assessed preoperatively and at 2 and 5 years after surgery. The SRS-22r consists of 22 items and six domains: function, pain, self-image, mental health, satisfaction, and subtotal. Each domain score ranges from 1 to 5 points, with higher scores indicating better outcomes. The ODI consists of 10 items: pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sex life, social life, and traveling. The score for each item ranges from 0 to 5 points, with lower score indicating better outcomes. Values (%) range from 0 to 100 (0–20, minimal disability; 21–40, moderate disability; 41–60, severe disability; 61–80, crippled; 81–100, bedbound). Section 8 (sex life) was eliminated from the assessment in this study because only a few patients answered it. The minimum clinically important difference (MCID) thresholds used were a change of score ≥ 14.96% for the ODI and a change of score ≥ 0.90 for function, 0.85 for pain, 1.05 for self-image, 0.70 for mental health, and 1.05 for subtotal domain in SRS-22r.[24–26]

Statistical analyses were performed using JMP software (version 14; SAS Institute Inc., Cary, NC). Data are presented as number or mean ± SD. The χ^2 tests were used to compare the categorical data and the rate of PJK and RF between the groups. The Mann-Whitney *U* test was used to compare the numerical data between the groups. The Wilcoxon signed-rank test was used to compare the numerical data within the group. For all tests, $P < 0.05$ was considered significant.

RESULTS

We performed short fusion for 29 of 54 patients. In the S-group, the UIV was L1 in 13 patients and L2 in 16 patients. Regarding the lower instrumented vertebra in the S-group, it was L5 in 15 patients and the sacrum or pelvis in 14 patients. The lower instrumented vertebra in the L-group was the pelvis in all patients. One patient in each group underwent revision surgery due to proximal junctional failure (S-group) and painful RF (L-group) during the follow-up period (Table 1). The rate of revision surgery was not statistically significantly different between the groups.

The long-term outcomes were assessed in the remaining 52 patients. An overview of the patient charac-

TABLE 1. Patients Who Underwent Revision Surgery

Characteristics	S-group	L-group	*P*
n/N (%)	1/29 (3.4)	1/25 (4.0)	0.915
Sex	Female	Female	NA
Age (years old)	76	68	NA
BMI (kg/m^2)	21.5	18.3	NA
Fused segments	L1-pelvis	T9-pelvis	NA
Time from index surgery (mo)	6	12	NA
Factor for revision surgery	PJF	RF	NA

BMI indicates body mass index; PJF, proximal junctional failure; RF, rod fracture.

TABLE 2. Preoperative Characteristic Comparison Between S-group and L-group

Variables	S-group (n = 28)	L-group (n = 24)	P
Sex (male:female)	5:23	3:21	0.591
Age (years old)	68.6 ± 6.2	69.4 ± 6.7	0.520
BMI (kg/m^2)	23.1 ± 3.3	23.1 ± 3.0	0.762
PI (degree)	50.8 ± 11.8	51.8 ± 11.6	0.755
LL (degree)	42.8 ± 20.0	42.3 ± 15.3	0.883
PI-LL (degree)	35.9 ± 16.6	38.2 ± 10.3	0.312
PT (degree)	23.1 ± 3.3	23.1 ± 3.0	0.762
SVA (mm)	102.3 ± 40.3	118.8 ± 55.0	0.287
CB (mm)	24.1 ± 25.2	26.4 ± 21.7	0.596
ODI (%)	47.4 ± 12.8	41.4 ± 16.3	0.186
SRS-22 subtotal	2.7 ± 0.4	2.7 ± 0.4	0.661
Function	2.5 ± 0.5	2.6 ± 0.6	0.796
Pain	3.2 ± 0.6	3.3 ± 0.7	0.479
Self-image	2.3 ± 0.7	1.9 ± 0.7	0.054
Mental health	3.0 ± 0.4	3.0 ± 0.4	0.983

Values are presented as number or mean ± SD.
BMI indicates body mass index; CB, coronal balance; LL, lumbar lordosis; ODI, Oswestry Disability Index; PI, pelvic incidence; PT, pelvic tilt; SRS, Scoliosis Research Society; SVA, sagittal vertical axis.

teristics is shown in Table 2. There was no significant difference in preoperative patients' demographics (age at the time of surgery, sex, body mass index), radiographic sagittal and coronal profile, and PROs (ODI, all domains of SRS-22r) between the groups. Spinal deformity was similarly corrected between the groups (Table 3). Significant loss of deformity correction in the sagittal plane was observed during the 2 years after surgery in the S-group (mean PI-LL: 17.3–23.8, $P = 0.003$; mean PT: 25.8–30.4, $P = 0.005$; mean SVA: 35.9–70.9, $p<0.001$). In the L-group, only SVA significantly increased during the same period (mean: 34.3–56.8, $p<0.001$). Nevertheless, at 2 years after surgery in both groups, PROs (ODI and all domains of SRS-22r) statistically significantly improved compared with baseline, and ODI (mean: 47.4–24.9 and 41.4–19.6) and self-image of SRS-22r (mean: 2.3–3.6 and 1.9–4.6) reached MCID (Table 4). In addition, ODI and domains of SRS-22r except for subtotal ($P = 0.043$) and pain ($P = 0.003$) were not statistically significantly different between the groups at 2 years after surgery.

Thereafter, although SVA in the S-group continued to increase significantly until 5-year follow-up (mean: 70.9–85.1, $P = 0.021$), other sagittal and coronal parameters in both groups did not significantly change during that period. PRO measurements showed that ODI and all domains did not reach MCID, although there was statistically significant change of ODI in the S-group ($P = 0.031$) and self-image of SRS-22r in both groups ($P = 0.045$ and 0.002) (Table 5). Regarding mechanical complications on radiographic examination until 5-year follow-up, PJK occurred more frequently in the S-group (42.9%) than in the L-group (12.5%, $P = 0.013$), whereas RF occurred more frequently in the L-group (20.8%) than in the S-group (10.7%, $P = 0.045$). Among the radiographic parameters at 5 years after surgery, LL and PI-LL were significantly different between the S-group (mean: 25.7 and 25.0, respectively) and the L-group (mean: 37.3 and 14.5, respectively; $P = 0.001$ and 0.041, respectively). Patients in the L-group reported statistically better clinical outcomes with statistical significance in ODI (mean 20.2) and SRS-22r (mean subtotal: 3.5; mean function: 3.3; mean pain: 3.9) than those in the S-group (mean: 29.8, 3.2, 2.9, and 3.6, respectively, $P = 0.013$, 0.006, 0.028 and 0.003, respectively) at 5-year follow-up (Table 6).

TABLE 3. Comparison of Immediately Postoperative Radiographic Parameters Between S-group and L-group

Variables	S-group (n = 28)	L-group (n = 24)	P
LL (degree)	33.4 ± 8.6	40.1 ± 10.5	0.063
PI-LL (degree)	17.3 ± 14.1	11.7 ± 11.2	0.295
PT (degree)	25.8 ± 12.3	25.9 ± 11.7	0.659
SVA (mm)	35.9 ± 32.5	34.3 ± 27.5	0.919
CB (mm)	14.3 ± 15.3	12.6 ± 15.3	0.664

Values are presented as mean ± SD.
CB indicates coronal balance; LL, lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; SVA, sagittal vertical axis.

DISCUSSION

The goals of ASD surgery are restoration of sagittal and coronal alignment and reduction of patient-reported pain and disability. Recently, minimally invasive multilevel LIF was introduced, and favorable outcomes can be obtained after surgery in terms of realignment and improvement in health-related quality of life.[12,13,27] However, the durability of satisfactory outcomes following ASD surgery using LIF has not been well-documented, especially after 5-year follow-up postoperatively.

In this study, we investigated radiographic and clinical outcomes at baseline and at 2 and 5 years after surgery. In addition, surgical outcomes were compared between short and long fusion because, to the best of our knowledge, there are no reports in the literature of long-term outcomes of short fusion in ASD. Radiographic examination showed that spinal deformity was similarly corrected between the groups according to our surgical indication and strategy when LIF was used. Follow-up radiographic examination revealed that loss of deformity correction mostly occurred during the 2 years after surgery. PI-LL, PT, and SVA in the S-group as well as SVA in the L-group, significantly increased during that period. Despite these radiographic changes, PROs had significantly improved in both groups at 2 years after surgery compared with those at baseline. Thereafter, only SVA in the S-group continued to increase significantly until 5-year follow-up, but all other radiographic parameters in both groups did not change significantly between 2 and 5 years after surgery, resulting in significant change in ODI and self-image of SRS-22r in the S-group without reaching MCID. Interestingly, self-image of SRS-22r in the L-group also significantly changed without reaching MCID during the same period. Finally, there was a significant difference in LL and PI-LL radiographically between the groups at 5 years after surgery. In association with these radiographic results, ODI and sub-

TABLE 4. Patient-reported Outcomes at Baseline and at 2 years After Surgery in the S-group and L-group

	S-group (n = 28)			L-group (n = 24)		
Variables	**Baseline**	**2YFU**	***P***	**Baseline**	**2YFU**	***P***
ODI (%)	47.4 ± 12.8	24.9 ± 14.7	<0.001*†	41.4 ± 16.3	19.6 ± 16.7	<0.001*†
SRS-22 subtotal	2.7 ± 0.4	3.4 ± 0.4	<0.001*	2.7 ± 0.4	3.6 ± 0.3	<0.001*
Function	2.5 ± 0.5	3.1 ± 0.4	<0.001*	2.6 ± 0.6	3.3 ± 0.4	0.002*
Pain	3.2 ± 0.6	3.6 ± 0.5	0.005*	3.3 ± 0.7	4.0 ± 0.3	<0.001*
Self-image	2.3 ± 0.7	3.6 ± 0.9	<0.001*†	1.9 ± 0.7	4.0 ± 0.6	<0.001*†
Mental health	3.0 ± 0.4	3.3 ± 0.3	0.008*	3.0 ± 0.4	3.2 ± 0.4	0.017*

Values are presented as mean ± SD.
*$P < 0.05$ is considered to be significant.
†MCID is reached.
ODI indicates Oswestry Disability Index; SRS, Scoliosis Research Society; YFU, year follow-up.

total function and pain of SRS-22r were significantly different between the groups at 5 years after surgery. However, satisfaction of SRS-22r was not significantly different between the groups, and ODI in S-group (29.8%) indicates moderate disability. Therefore, in both groups, gain in health-related quality of life after ASD surgery using LIF was maintained between 2- and 5-year follow-up with a minimal revision rate, despite the moderate rate of mechanical complications and the aggravation of spinal sagittal alignment. Furthermore, clinical outcomes were comparable between the groups, despite inferior sagittal profile in the S-group at 5-year follow-up. Fusion to the thoracic spine could be avoided in patients without degenerative changes at the thoracolumbar junction.

Adogwa et al[28] reported that PROs at 2-year follow-up accurately predicted those at 5-year follow-up in patients who underwent complex spinal fusion (≥ 5 levels), although they did not describe the pathology. In addition, Arima et al[29] demonstrated that 2-year PROs strongly correlated with 5-year PROs in patients with degenerative ASD who underwent corrective fusion surgery from the thoracic spine to the pelvis using a variety of surgical techniques including LIF. Our results in patients undergoing long fusion using LIF were consistent with those of the previous reports. Regarding the impact of length of spinal fusion on surgical outcomes for ASD, a comparative study with a minimum 2-year follow-up between short (≤ 3 levels) and long (≥ 4 levels) fusion for degenerative lumbar scoliosis reported no significant difference in clinical outcomes 2 years after surgery. This was despite greater aggravation of SVA and more frequent occurrence of PJK in short fusion than in long fusion, as well as more frequent occurrence of implant-related complications in long fusion than in short fusion.[30] Our findings were consistent with the results of that study. Loss of deformity correction mostly occurred during the first 2 years in both groups and was greater in the S-group than in the L-group, which mostly depended on more frequent PJK in the S-group and more frequent RF in the L-group. However, there was no clinically significant difference between the groups.

Increased mechanical stress on vertebrae and intervertebral disks in the thoracolumbar junction of the spine with sagittal imbalance was shown in a previous biomechanical study.[31] Other biomechanical investigations of long spinal fusion to the pelvis have shown increased mechanical stress in the lower lumbar lesion.[32,33] These biomechanical findings also reinforce our findings of more

TABLE 5. Radiographic and Clinical Outcomes at 2 and 5 Years After Surgery in the S- and L-groups

	S-group (n = 28)			L-group (n = 24)		
Variables	**2YFU**	**5YFU**	***P***	**2YFU**	**5YFU**	***P***
LL (degree)	26.9 ± 15.1	25.7 ± 13.4	0.167	38.4 ± 8.1	37.3 ± 9.9	0.376
PI-LL (degree)	23.8 ± 18.8	25.0 ± 16.5	0.167	13.4 ± 11.2	14.5 ± 14.7	0.376
PT (degree)	30.4 ± 15.1	30.5 ± 14.9	0.925	27.0 ± 9.1	27.7 ± 10.7	0.483
SVA (mm)	70.9 ± 53.1	85.1 ± 61.2	0.021*	56.8 ± 35.8	66.8 ± 39.4	0.073
CB (mm)	14.4 ± 15.9	14.4 ± 16.5	0.967	14.3 ± 15.2	15.3 ± 16.4	0.687
ODI (%)	24.9 ± 14.7	29.8 ± 14.2	0.031*	19.6 ± 16.7	20.2 ± 16.0	0.829
SRS-22 subtotal	3.4 ± 0.4	3.2 ± 0.4	0.062	3.6 ± 0.3	3.5 ± 0.3	0.123
Function	3.1 ± 0.4	2.9 ± 0.5	0.141	3.3 ± 0.4	3.3 ± 0.4	0.935
Pain	3.6 ± 0.5	3.6 ± 0.5	0.887	4.0 ± 0.3	3.9 ± 0.4	0.133
Self-image	3.6 ± 0.9	3.2 ± 0.8	0.045*	4.0 ± 0.6	3.6 ± 0.6	0.002*
Mental health	3.3 ± 0.3	3.1 ± 0.5	0.090	3.2 ± 0.4	3.3 ± 0.3	0.356
Satisfaction	3.8 ± 0.7	3.8 ± 0.8	0.800	3.9 ± 0.7	3.8 ± 0.8	0.119

Values are presented as mean ± SD.
*$P < 0.05$ is considered to be significant.
CB indicates coronal balance; LL, lumbar lordosis; ODI, Oswestry Disability Index; YFU, year follow-up; PI, pelvic incidence; PT, pelvic tilt; SRS, Scoliosis Research Society; SVA, sagittal vertical axis.

TABLE 6. Comparison of Radiographic and Clinical Outcomes at 5 Years After Surgery Between S-group and L-group

Variables	S-group (n = 28)	L-group (n = 24)	*P*
LL (degree)	25.7 ± 13.4	37.3 ± 9.9	0.001*
PI-LL (degree)	25.0 ± 16.5	14.5 ± 14.7	0.043*
PT (degree)	30.5 ± 14.9	27.7 ± 10.7	0.666
SVA (mm)	85.1 ± 61.2	66.8 ± 39.4	0.312
CB (mm)	14.4 ± 16.5	15.3 ± 16.4	0.764
PJK, n/N (%)	12/28 (42.9)	3/24 (12.5)	0.013*
Rod fracture, n/N (%)	3/28 (10.7)	5/24 (20.8)	0.045*
ODI (%)	29.8 ± 14.2	20.2 ± 16.0	0.013*
SRS-22 subtotal	3.2 ± 0.4	3.5 ± 0.3	0.006*
Function	2.9 ± 0.5	3.3 ± 0.4	0.028*
Pain	3.6 ± 0.5	3.9 ± 0.4	0.003*
Self-image	3.2 ± 0.8	3.6 ± 0.6	0.097
Mental health	3.1 ± 0.5	3.3 ± 0.3	0.061
Satisfaction	3.8 ± 0.8	3.8 ± 0.8	0.563

Values are presented as number or mean ± SD.

*$P < 0.05$ is considered to be significant.

CB indicates coronal balance; LL, lumbar lordosis; ODI, Oswestry Disability Index; YFU, year follow-up; PI, pelvic incidence; PJK, proximal junctional kyphosis; PT, pelvic tilt; RF, rod fracture; SRS, Scoliosis Research Society; SVA, sagittal vertical axis.

frequent occurrence of PJK in the S-group as well as more frequent occurrence of RF in the L-group.

Schwab et al[34] indicated the realignment objectives: SVA <5 cm, PT <25 degrees, and PI-LL <10 degrees. Although the radiographic parameters in the current study were out of these threshold values, especially in the S-group, their realignment objectives were based on the data from younger patients than those in our study. All values of these sagittal parameters increased with age in healthy subjects aged over 50 years with or without low back pain.[35] Furthermore, according to a recent report, there are discrepancies in the perception and satisfaction for surgical outcomes between patients and surgeons, which are independent of radiographic outcomes.[36] Older patients might therefore tolerate sagittal alignment greater than realignment objectives, which may result in moderate disability in the S-group at 5 years after surgery.

Despite the limitations of the current study including the small number of patients and the lack of data on stiffness-related functional disability, we believe that this is the first comparative analysis of short and long fusion for ASD using LIF with a minimum 5-year follow-up. Gain in health-related quality of life after ASD surgery using LIF was maintained between 2- and 5-year follow-ups in both short and long fusion. Although long fusion secures favorable long-term outcomes, short fusion can be considered as an option for patients without degenerative changes at the thoracolumbar junction. A further comparative study between the patients treated with and without LIF is needed to corroborate our findings.

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