




Radiographic and Clinical Outcomes From the Use of S2 Alar Screws in Surgery for Adult Spinal Deformity

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Abstract

Study Design: Retrospective.

Objectives: To evaluate the efficacy of S2 alar screws in surgery for correction of adult spinal deformity (ASD).

Methods: We retrospectively reviewed the cases of 23 patients (mean follow-up: 18.5 months, minimum 12 months) who underwent corrective surgery for ASD using S2 alar screws as anchors for instrumentation of lower vertebrae. The background of the patients and their spinopelvic parameters (pelvic incidence [PI], pelvic tilt [PT], lumbar lordosis [LL], thoracic kyphosis [TK], sagittal vertical axis [SVA], and PI-LL) were evaluated.

Results: LL was improved from $9.7 \pm 20.5^\circ$ and SVA from 141.0 ± 64.0 mm before surgery to $39.0 \pm 9.6^\circ$ and 51.7 ± 40.8 mm immediately after surgery, respectively, and $38.2 \pm 12.7^\circ$ and 70.5 ± 59.2 mm at final follow-up. In 13 patients without sufficient correction (postoperative PI-LL $\geq 10^\circ$), bone mineral density and postoperative LL were significantly less, and PI, PI-LL, and PT were significantly greater than in patients with postoperative PI-LL $< 10^\circ$, suggesting that these are risk factors for under-correction. In 5 patients, SVA increased more than 40 mm during follow-up. Postoperative LL was significantly less (31.4° vs 41.0°) and postoperative PI-LL was significantly greater (21.6° vs 9.3°) in these patients, suggesting a PI-LL mismatch induces postoperative progression of global malalignment.

Conclusions: Use of S2 alar screws as anchors for instrumentation in ASD surgery should be restricted. Their use might be an option for patients with low PI, and without severe osteoporosis, in whom efficient surgical correction can be obtained.

Keywords

S2 alar screw, adult spinal deformity, spinopelvic parameter

Introduction

Selecting the patient and the optimal fusion level for surgery to correct adult spinal deformity (ASD) is especially challenging. Surgery for ASD is of substantial benefit for elderly patients,¹⁻³ and extension of long fusions to the sacrum to the pelvis with iliac screws results in good sagittal alignment with less correction loss and good clinical outcomes.^{4,5} By contrast, several complications such as nonunion, implant prominence, screw loosening, infection, arterial or the nerve injury, and implant failures are reported after sacropelvic fusion.⁶ High rates of nonunion have been reported after long spinal fusions to the sacrum in attempts at lumbosacral fusion, because of a high

mechanical demand and short, wide, cancellous pedicles at S1.⁷⁻⁹ In addition to S1 pedicle screws, there are several other methods for lumbosacral fixation, such as the Galveston technique, iliac screws, S2-alar-iliac (S2AI) screws, and S2 alar screws. Although the use of iliac screws or S2AI screws should

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Table 1. Patients' Background Data.

Variables	Value
Number	23
Age, years (range)	71.3 ± 7.7 (50-80)
Sex, male–female	2:21
Preoperative BMI, kg/m ² (range)	24.2 ± 3.8 (17.4-31.5)
Preoperative BMD, g/cm ² (range)	0.88 ± 0.29 (0.49-1.47)
Number of fused levels (range)	8.5 ± 0.7 (8-10)
L5-S1 interbody fusion	+: 16; -: 7
Osteotomy (PSO or pVCR)	+: 4; -: 19
OLIF	+: 14; -: 9
Follow-up period (range)	18.5 ± 6.8 (12-30)
Reoperation rate	21.7% (5/23 cases)

Abbreviations: BMI, body mass index; BMD, bone mineral density; PSO, pedicle subtraction osteotomy; pVCR, posterior vertebral column resection; OLIF, oblique lumbar interbody fusion.

provide rigid fixation at the lumbosacral junction and reduce nonunion at the lumbosacral junction, several complications have been reported, including sacroiliac joint (SIJ) pain, breach of the screw, and wound dehiscence, even if these complications are less frequent when S2AI screws are used.^{5,10} By contrast, S2 alar screws combined with S1 pedicle screws show higher resistance to loosening or breaking against compressive, tensional, and torsional loads than S1 pedicle screws alone,^{11,12} but the clinical results or complications arising from the use of S2 alar screws in surgery to correct ASD remain largely unknown. The objectives of the present study were to investigate the clinical and radiographic outcomes after at least a 12-month follow-up, to clarify the impact of the S2 screws on the degree of correction, L5-S1 fusion status, and any related periscrew lucency or loosening, and indications for the use of S2 screws in surgery for ASD.

Materials and Methods

Patient Population

The present study was conducted under a protocol approved by the institutional review board of Kitasato University School of Medicine. We conducted a retrospective review of clinical and radiological data from a single institution obtained between August 2013 and January 2015. Twenty-three patients underwent surgery for ASD to fuse the lower thoracic spine to the sacrum using S2 alar screws. All patients underwent surgery for their deformity. The inclusion criteria for the present study were as follows: patients with (1) age >50 years, (2) fusion of the lower thoracic spine to the sacrum, and (3) 1-year minimum follow-up. Patients with (1) prior spinal surgery or (2) surgery not performed for correction of ASD were excluded. The background data for the included patients is shown in Table 1.

Surgical Procedure

All patients underwent corrective surgery to restore sagittal balance. The patients were placed in a prone position under

general anesthesia with sevoflurane delivered endotracheally. A standard posterior midline incision was made, the vertebrae targeted for fusion were exposed, and pedicle screws (CD Horizon Solera; Medtronic Sofamor Danek, Minneapolis, MN) were inserted into the segments targeted for fusion under a lateral C-arm view (Arcadis Orbic 3D; Siemens Medical Solutions, Erlangen, Germany). Correction was performed to achieve an ideal lordotic alignment in which PI-LL within modifier "0" had a value <10° in the Scoliosis Research Society (SRS)-Schwab ASD classification.¹³

To achieve ideal sagittal alignment, various additional surgical procedures were performed. Oblique lumbar interbody fusion (OLIF) using 6-degree lordotic-angled polyetheretherketone (PEEK) cages (Clydesdale; Medtronic Sofamor Danek) was used in 14 patients (2 levels in 7 patients, and 3 levels in 7 patients). In these patients, posterior column resection was added at the same level of OLIF. Pedicle subtraction osteotomy at L4 with an adjacent interbody cage was used in 2 patients.¹⁴ Posterior vertebral column resection was performed in 1 patient with rigid kyphosis.¹⁵ In all patients, partial or total posterior column osteotomy was used to increase the local lordotic angle if necessary. In 16 patients, L5-S1 transforaminal lumbar interbody fusion (TLIF) was achieved using angulated PEEK cages (Capstone Control; Medtronic Sofamor Danek). Posterior rodding was used together with sublaminar cables (Nesplon Cable System; Alfresa, Tokyo, Japan). Laminae, spinal processes, and facets were decorticated, and morselized cancellous allograft and local autograft from the posterior decompression site were transplanted. Iliac crest was not harvested from any patient.

Insertion Technique for S2 Alar Screws

To preserve muscle coverage over instrumentation, the sacrum was exposed with minimum dissection, and the posterior S1 foramina and the cranial border of the posterior S2 foramina were recognized as landmarks after inserting S1 pedicle screws. Identifying the lateral limits with a blunt probe inserted into the SIJ, the S2 alar screws were generally located in-line with S1 pedicle screws, which usually indicated a slight medial deviation of the S2 alar screw head in relation to the S1 pedicle screw head. An awl was inserted in a 30° to 45° lateral and inferior direction to a depth of around 20 mm into the sacral bone, and a probe was used for further insertion until contact with the cortical surface of the sacral bone, at approximately 40 to 45 mm. Self-tapping screws with a diameter of 6.5 to 7.5 mm and 35 to 45 mm in length were inserted in the same trajectory of the probe, taking care not to breach the cortical bone.

Clinical and Radiological Assessment

Radiographic evaluation was performed using anteroposterior and lateral standing X-ray imaging before surgery, immediately after surgery, and 1, 3, 6, and 12 months, and then every 6 months after surgery. Radiographic parameters including the pelvic incidence (PI), lumbar lordosis (LL), T5-T12 thoracic

kyphosis (TK), L1-S1 pelvic tilt (PT), sagittal vertical axis (SVA), and distance between the vertical line beginning at the center of the C7 body and central sacral vertical line (C7-CSVL) were determined. To evaluate the local alignment at the level of L5-S1, disc angle was calculated as the angle between the lower endplate of L5 and the upper endplate of the S1. Lordosis is recorded as a negative value and kyphosis as a positive value.

Computed tomography (CT) performed 1 year postoperatively was assessed to determine instrumentation and fusion-related radiographic outcomes. Periscrew lucency <2 mm or loosening of the S2 alar screws and the status of L5-S1 interbody fusion was evaluated. Osseous fusion was defined as bony bridging spanning the disc space in patients in whom an L5-S1 interbody cage was used. SIJ degeneration was also evaluated using CT, and was defined as 1 or more of the following CT findings: sclerotic changes throughout the entire joint area (more than 5 mm in the ilium or more 3 mm in the sacrum), erosion, extra-articular osteophyte formation extending beyond the SIJ, joint space narrowing more than 2 mm, and subchondral cysts.^{16,17}

All X-ray images and CT were reviewed independently by 2 authors (TI and MM). Data was collected and analyzed separately. For situations in which the radiographic outcomes differed among reviewers, the case was discussed and a consensus was reached. To determine the health-related quality of life of the patients, the Oswestry Disability Index (ODI) was measured before surgery and at the final follow-up.¹⁸ The reoperation rate was also determined.

Comparison Between Groups Classified by Radiological Findings

To evaluate factors favorable for achieving sufficient lordosis by surgery, PI-LL seen in X-ray images taken just after surgery was evaluated, and patients were classified into 2 groups, PI-LL <10° and PI-LL ≥10°. To evaluate the persistence of the postoperative sagittal alignment, degree of the change in SVA from immediately after surgery to final follow-up was calculated, and patients were classified into 2 groups, SVA increase <40 mm and ≥40 mm. Patients were further divided into 2 groups: one with and the second without S2 alar screw loosening during the follow-up period. Between each group described above, age, sex, body mass index (BMI), preoperative bone mineral density (BMD) and T-score in the femoral neck, additional surgical methods, and reoperation rate were compared. We compared the value of each radiological parameter obtained before surgery, just after surgery, and at the final follow-up.

Statistical Analyses

Statistical analyses were conducted using JMP software (version 11.0; SAS Institute, Cary, NC). Results are expressed as means and standard deviation. A nonparametric Mann-Whitney *U* test was used to compare normally distributed data between the

Table 2. Changes in Radiological Parameters and ODI.

Variables	Preoperative	Postoperative	Final Follow-up (18.6 ± 6.8 Months)
Spinopelvic parameters			
Pelvic incidence (°)	51.0 ± 7.9	50.9 ± 8.6	51.7 ± 8.3
Pelvic tilt (°)	37.3 ± 10.5	24.4 ± 8.2**	26.5 ± 10.5**
Lumbar lordosis (°)	9.7 ± 20.5	39.0 ± 9.6**	38.2 ± 12.7**
Thoracic kyphosis (°)	29.2 ± 15.5	35.3 ± 10.1	40.0 ± 13.9*
Global alignment			
Sagittal vertical axis (mm)	141.0 ± 64.0	51.7 ± 40.8**	70.5 ± 59.2**
C7-CSVL (mm)	36.0 ± 27.9	19.5 ± 11.7*	19.7 ± 15.6*
PI-LL (°)	41.3 ± 21.9	12.0 ± 11.1**	12.6 ± 11.9**
L5-S1 disc angle	9.1 ± 7.0	7.5 ± 3.9	5.6 ± 5.1
ODI	50.2 ± 12.0	—	29.2 ± 17.0

Abbreviations: CSVL, central sacral vertical line; PI, pelvic incidence; LL, lumbar lordosis; ODI, Oswestry Disability Index.

P* < .05, *P* < .01 compared with preoperative value.

groups (age, BMI, preoperative BMD, T-score, radiological parameters, ODI, and follow-up period). A χ^2 test was used to compare sex, additional surgical methods, and reoperation rate between the groups. *P* < .05 was considered significant.

Results

On average, for all 23 patients, PI-LL was corrected from preoperative 41.3 ± 21.9° to 12.0 ± 11.1° just after surgery, and maintained at 12.6 ± 11.9° at final follow-up, and accordingly, PT and SVA were corrected from preoperative 37.3 ± 10.5° and 141.0 ± 64.0 mm to 24.4 ± 8.2° and 51.7 ± 40.8 mm after surgery, respectively, and 26.5 ± 10.5° and 70.5 ± 59.2 mm at final follow-up (Table 2). Table 3 indicates SRS-Schwab classifications of ASD.¹³ Although correction surgery was performed with the aim of achieving PI-LL with a “0” (within 0°) sagittal modifier classification, only 10 cases were classified as being “0,” 8 cases were classified as having a “+” (moderate 10° to 20°) modifier, and 5 cases as having a “++” (marked >20°) modifier just after surgery and at final follow-up. For the global alignment, all cases were classified into modifier “+” (SVA 4-9.5 cm; *n* = 6) or “++” (SVA >9.5 cm; *n* = 17) at baseline, and corrected into modifier “0” (SVA <4 cm; *n* = 9) or “+” (*n* = 13) except in one case just after the surgery. At final follow-up, global alignment increased from “0” to “+” in 3 patients and from “+” to “++” in 1 patient. In PT, at baseline, 1 patient was classified having a “0” (<20°) modifier, 3 patients as having “+” (20° to 30°), and 19 patients as “++” (>30°). After surgery, only 4 patients were classified as having “0” PT and 17 patients as having a “+” sagittal modifier. The results of classification using the 3 sagittal modifiers indicate correction using S2 alar screws might be insufficient to achieve an ideal LL in most patients, and insufficient for subsequent ideal PI-LL, SVA, and PT.

Tables 4 and 5 show a comparison of the background of the patients and the spinopelvic parameters of the group with

Table 3. Patients' Categorization According to SRS-Schwab Classification.

	Preoperative	Postoperative	Final Follow-up (18.6 ± 6.8 Months)
PI-LL			
<10°	1	10	10
10-20°	3	8	8
>20°	19	5	5
SVA			
<4 cm	0	9	6
4-9.5 cm	6	13	15
>9.5 cm	17	1	2
PT			
<20°	1	4	3
20-30°	3	17	15
>30°	19	2	5

Abbreviations: PI, pelvic incidence; LL, lumbar lordosis; SVA, sagittal vertical axis; PT, pelvic tilt.

Table 4. Difference of Patients' Characteristics Classified by PI-LL.

	PI-LL <10°	PI-LL ≥10°	P
Number	10	13	
Age, years (mean ± SD)	71.1 ± 8.6	71.5 ± 7.4	.91
Sex, male–female	2:8	0:13	.18
Preoperative BMI (kg/m ²)	23.3 ± 3.8	24.9 ± 3.7	.69
Preoperative BMD (g/cm ²)	1.04 ± 0.31	0.74 ± 0.17	.03
T-score	-1.5 ± 1.3	-1.6 ± 1.0	.86
L5-S1 PLIF	+: 8, -: 2	+: 8, -: 5	.97
L5-S1 fusion rate	87.5%	62.5%	.67
Osteotomy (PSO or pVCR)	+: 2, -: 8	+: 2, -: 11	.77
OLIF	+: 6, -: 4	+: 8, -: 5	.94
Reoperation rate	20.0% (2/10)	23.1% (3/13)	.86
ODI			
Preoperative	53.7 ± 10.7	45.7 ± 12.8	.20
Last follow-up	29.1 ± 21.1	31.1 ± 15.6	.81

Abbreviations: PI, pelvic incidence; LL, lumbar lordosis; BMI, body mass index; BMD, bone mineral density; PLIF, posterior lumbar interbody fusion; PSO, pedicle subtraction osteotomy; pVCR, posterior vertebral column resection; OLIF, oblique lumbar interbody fusion; ODI, Oswestry Disability Index. Boldface indicates significant difference with *P* value < .05.

PI-LL <10° and of the group with PI-LL ≥10° just after surgery. Preoperative BMD is significantly lower in the group with PI-LL ≥10° (Table 4). Pre- and postoperative PI and PI-LL were significantly different, and postoperative PT and LL were significantly different (Table 5). The reoperation rate was not significantly different between the groups (20.0% in the group with PI-LL <10° compared with 23.1% in the group with PI-LL ≥10°). In the group with PI-LL <10°, 2 patients were reoperated on to reinsert misplaced screws and to treat a surgical site infection. By contrast, in the group with PI-LL ≥10°, reoperation was performed to correct backout of bilateral S1 and S2 screws in 2 patients, and proximal junctional failure (PJF) in 1 patient.

Patients in the group with an SVA increase <40 mm and the group with SVA increase ≥40 mm are compared in Tables 6

Table 5. Difference of Patients' Radiological Evaluations Classified by PI-LL.

	PI-LL <10°	PI-LL ≥10°	P
Number of patients	10	13	
PI			
Preoperative	46.9 ± 7.4	54.5 ± 6.7	.02
Postoperative	46.7 ± 7.8	54.2 ± 8.0	.04
Last follow-up	48.2 ± 9.2	54.4 ± 6.7	.07
PT			
Preoperative	35.7 ± 10.9	38.6 ± 10.4	.53
Postoperative	20.4 ± 8.1	27.5 ± 7.0	.03
Last follow-up	21.2 ± 9.2	30.5 ± 9.9	.03
LL			
Preoperative	17.0 ± 24.1	3.7 ± 15.4	.13
Postoperative	43.6 ± 6.3	35.3 ± 10.3	.03
Last follow-up	44.9 ± 8.7	32.6 ± 13.1	.01
TK			
Preoperative	34.7 ± 16.2	24.9 ± 14.2	.15
Postoperative	40.5 ± 12.2	31.4 ± 6.0	.05
Last follow-up	45.9 ± 13.6	35.5 ± 13.0	.08
PI-LL			
Preoperative	29.9 ± 24.4	50.8 ± 14.5	.02
Postoperative	3.1 ± 5.7	17.3 ± 7.7	<.01
Last follow-up	3.3 ± 4.6	20.4 ± 10.4	<.01
SVA			
Preoperative	129.0 ± 64.4	137.8 ± 49.1	.72
Postoperative	42.3 ± 28.6	58.8 ± 48.0	.35
Last follow-up	54.8 ± 48.7	82.6 ± 65.4	.27
C7-CSVL			
Preoperative	33.5 ± 26.5	36.5 ± 30.6	.81
Postoperative	19.8 ± 13.3	19.2 ± 10.9	.91
Last follow-up	20.7 ± 18.4	19.0 ± 13.8	.80
Loosening of S2 alar screw	+6, -4	+7, -6	.77
L5-S1 angle			
Preoperative	11.0 ± 8.2	7.6 ± 6.1	.27
Postoperative	9.7 ± 4.0	5.5 ± 2.9	.01
Last follow-up	8.8 ± 4.0	3.5 ± 4.4	<.01

Abbreviations: PI, pelvic incidence; LL, lumbar lordosis; PT, pelvic tilt; TK, thoracic kyphosis; SVA, sagittal vertical axis; CSVL, central sacral vertical line. Boldface indicates significant difference with *P* value < .05.

and 7. There was no significant difference in the background of the patients or surgical method between the 2 groups (Table 6). Radiological comparison showed preoperative TK, and postoperative PI and PI-LL, were significantly different between the groups. The SVA was significantly longer in the group with an SVA increase ≥40 mm (151.8 ± 75.7 mm vs 50.2 ± 29.4 mm; Table 7). Reoperation rate was higher in the group with SVA increase ≥40 mm, although not significantly different (40.0% vs 16.7%). In the group with an increase in SVA ≥40 mm, 2 patients were reoperated on to correct backout of S1 and S2 screws. In the group with an increase in SVA <40 mm, 3 patients underwent reoperation, specifically to reinsert a misplaced screw, for surgical site infection, and to correct PJF.

L5-S1 angle was significantly larger in patients in the group with PI-LL <10° than in those in the group with PI-LL ≥10° both at just after the surgery (9.7 ± 4.0° vs 5.5 ± 2.9°) and at the final follow-up (8.8 ± 4.0° vs 3.5 ± 4.4°; Table 5).

Table 6. Difference of Patients' Characteristics Classified by Increase of SVA.

	SVA Increase <40 mm	SVA Increase ≥40 mm	P
Number	18	5	
Age years, mean ± SD	70.4 ± 8.4	74.6 ± 3.0	.29
Sex, male–female	2:16	0:5	.44
Preoperative BMI	24.0 ± 3.9	25.1 ± 3.2	.59
Preoperative BMD	0.89 ± 0.31	0.85 ± 0.21	.81
T-score	-1.6 ± 1.1	-1.5 ± 1.2	.89
L5-S1 PLIF	+: 11, -: 7	+: 5, -: 0	.97
L5-S1 fusion rate	81.8%	60.0%	.35
Osteotomy (PSO or pVCR)	+: 3, -: 15	+: 1, -: 4	.86
OLIF	+: 10, -: 8	+: 4, -: 1	.32
Reoperation rate	16.7% (3/18)	40.0% (2/5)	.26
ODI			
Preoperative	49.3 ± 12.5	53.0 ± 11.4	.60
Last follow-up	25.1 ± 16.1	46.4 ± 8.4	.02

Abbreviations: SVA, sagittal vertical axis; BMI, body mass index; BMD, bone mineral density; PLIF, posterior lumbar interbody fusion; PSO, pedicle subtraction osteotomy; pVCR, posterior vertebral column resection; OLIF, oblique lumbar interbody fusion; ODI, Oswestry Disability Index. Boldface indicates significant difference with *P* value < .05.

Additionally, there was a significant difference in L5-S1 angle between patients in the group with an SVA increase <40 mm and those in the group with an SVA increase ≥40 mm at the final follow-up ($6.7 \pm 3.9^\circ$ vs $1.5 \pm 7.2^\circ$; Table 7). These results suggest that a sufficient increase in the L5-S1 angle is important for achieving an ideal LL during corrective surgery, and that deterioration of the L5-S1 angle could induce a failure in global alignment.

For 21 patients, we evaluated CT obtained 1 year after surgery. The exception was for 2 patients who needed revision surgery for backout of S2 alar screws before 1 year of follow-up. In a total of 42 screws, 12 (28.6%) showed loosening, and 10 (23.8%) showed a lucent clear zone of <2 mm around the screw. Loosening occurred in 3 patients with an L5-S1 TLIF cage, and 3 patients without. A clear zone around the screws was shown in 4 patients with an L5-S1 TLIF cage, and 1 patient without. S2 alar screw loosening occurred in more than half of patients during their follow-up (13/23 patients). BMI was significantly less (22.6 ± 3.1 vs 26.1 ± 3.7) and T-score tended to be lower (-2.0 ± 1.16 vs -0.96 ± 0.68) in patients with S2 alar screw loosening than in those without S2 alar screw loosening. In the 15 patients with an L5-S1 TLIF cage, the fusion rate was 80.0% (12/15 patients), but fusion rate was significantly less in patients with S2 screw loosening than in those without screw loosening (30.8% vs 100%; Tables 8 and 9). No patients showed any radiographic evidence for progressive degeneration of the SIJ.

ODI was not significantly different between patients with PI-LL <10° and those with PI-LL ≥10° before surgery and at the final follow-up. ODI score was significantly worse in patients with an SVA increase ≥40 mm

Table 7. Difference of Patients' Radiological Evaluations Classified by Increase of SVA.

	SVA Increase <40 mm	SVA Increase ≥40 mm	P
Number	18	5	
PI			
Preoperative	50.6 ± 8.0	52.4 ± 7.4	.66
Postoperative	50.3 ± 8.6	53.0 ± 9.4	.55
Last follow-up	51.7 ± 8.2	51.6 ± 9.6	.98
PT			
Preoperative	36.5 ± 10.5	41.0 ± 9.9	.48
Postoperative	23.7 ± 6.0	27.0 ± 14.3	.45
Last follow-up	26.2 ± 8.0	27.4 ± 18.2	.83
LL			
Preoperative	12.7 ± 19.7	-3.5 ± 21.0	.13
Postoperative	41.0 ± 7.8	31.4 ± 12.6	.04
Last follow-up	41.1 ± 9.1	25.0 ± 17.1	<.01
TK			
Preoperative	31.7 ± 15.5	20.0 ± 13.2	.13
Postoperative	36.9 ± 10.7	29.6 ± 4.3	.15
Last follow-up	45.6 ± 13.6	35.5 ± 13.0	.08
PI-LL			
Preoperative	37.9 ± 20.1	57.8 ± 22.8	.07
Postoperative	9.3 ± 7.9	21.6 ± 16.3	.03
Last follow-up	10.6 ± 8.4	30.0 ± 26.2	.01
SVA			
Preoperative	128.4 ± 52.1	169.6 ± 66.9	.16
Postoperative	44.1 ± 28.7	79.0 ± 66.8	.09
Last follow-up	50.2 ± 29.4	151.8 ± 75.7	<.01
C7-CSVL			
Preoperative	36.7 ± 30.3	30.2 ± 15.0	.65
Postoperative	17.4 ± 6.3	22.6 ± 16.3	.66
Last follow-up	22.6 ± 16.3	9.6 ± 6.9	.10
Loosening of S2 alar screw	+10, -8	+3, -2	.86
L5-S1 angle			
Preoperative	9.3 ± 7.8	8.2 ± 2.9	.76
Postoperative	7.4 ± 3.7	7.9 ± 5.1	.80
Last follow-up	6.7 ± 3.9	1.5 ± 7.2	.04

Abbreviations: SVA, sagittal vertical axis; PI, pelvic incidence; PT, pelvic tilt; LL, lumbar lordosis; TK, thoracic kyphosis; CSVL, central sacral vertical line. Boldface indicates significant difference with *P* value < .05.

than in those with an increase <40 mm at the final follow-up (46.4 ± 8.4 vs 25.1 ± 16.1). Moreover, ODI score at final follow-up was significantly improved in patients in the group with an SVA increase <40 mm compared with their score before surgery.

Discussion

In the present study, we found that LL and PI-LL were significantly improved after correction surgery with S2 alar screws. The postoperative PI-LL and SVA (SRS-Schwab sagittal modifier classification) in less than half of patients was classified as "0." The correction of PT in 17 patients (73.9%) was limited to "+," and was corrected to "0" in only 4 patients. Patients underwent surgery to improve PI-LL to <10°. However, the consequent undercorrection of SVA and PT suggests S2 alar

Table 8. Difference of Patients' Characteristics Classified by Loosening of S2 Alar Screw.

	Loosening –	Loosening +	P
Number	10	13	
Age, years (mean ± SD)	68.7 ± 10.5	73.3 ± 4.0	.16
Sex, male–female	1:9	1:12	.85
Preoperative BMI (kg/m ²)	26.1 ± 3.7	22.6 ± 3.1	.02
Preoperative BMD (g/cm ²)	0.85 ± 0.31	0.91 ± 0.27	.24
T-score	–0.96 ± 0.68	–2.0 ± 1.16	.86
L5-S1 TLIF	+: 7, –: 3	+: 9, –: 4	.97
L5-S1 fusion rate	100.0%	55.6%	.04
Osteotomy (PSO or pVCR)	+: 3, –: 7	+: 1, –: 12	.16
OLIF	+: 5, –: 5	+: 9, –: 4	.35
Reoperation rate	10.0% (1/10)	30.8% (4/13)	.23
ODI			
Preoperative	54.0 ± 14.5	47.9 ± 10.3	.19
Final follow-up	23.1 ± 15.4	34.7 ± 17.3	.12

Abbreviations: BMI, body mass index; BMD, bone mineral density; TLIF, transforaminal lumbar interbody fusion; PSO, pedicle subtraction osteotomy; pVCR, posterior vertebral column resection; OLIF, oblique lumbar interbody fusion; ODI, Oswestry Disability Index.

Boldface indicates significant difference with *P* value < .05.

screws are not sufficient to correct LL to an ideal level. When patients were classified into 2 groups, those with PI-LL <10° and those with PI-LL ≥10°, 13 (57%) were classified into the group with PI-LL ≥10°. Preoperative BMD was significantly lower (1.04 ± 0.31 g/cm² vs 0.74 ± 0.17 g/cm²) and PI was significantly greater (46.9 ± 7.4° vs 54.5 ± 6.7°) in the PI-LL ≥10° group. These results suggest that in patients with greater PI, there is more extensive LL to be corrected, and in patients with lower BMD, S2 alar screws are less useful to correct LL using cantilever forces because of the biomechanical weakness of their bone.

When patients were classified into 2 groups, the first group with an increase of SVA <40 mm, and the second group with an increase of SVA ≥40 mm, to evaluate whether S2 alar screws can maintain corrected alignment in follow-up periods longer than 1 year, we found SVA increased by ≥40 mm in 5 patients, whose background and surgical treatment were not significantly different from the other patients (Table 6). Radiologically, no parameters were significantly different preoperatively, but LL and PI-LL were significantly different between the 2 groups after surgery. SVA was significantly longer in the group with an increase in SVA ≥40 mm at final follow-up (151.8 ± 75.7 mm vs 50.2 ± 29.4 mm; Table 7), indicating that patients with undercorrection of LL that did not match PI just after the surgery have increased SVA subsequently at the final follow-up. Of the 5 patients in the group with an increase in SVA ≥40 mm, 3 showed loosening of S1 and S2 screws, even with use of an L5-S1 interbody cage, and revision surgery using iliac screws was needed, although one patient refused the revision surgery. A clear zone indicating loosening of S2 alar screws was noted in 13 patients at 1 year after surgery, but these findings were not correlated with BMD or use of an L5-S1 TLIF cage. Even using an L5-S1 TLIF cage, the fusion

Table 9. Difference of Patients' Radiological Evaluations Classified by Loosening of S2 Alar Screw.

	Loosening –	Loosening +	P
Number	10	13	
PI			
Preoperative	50.5 ± 8.4	51.5 ± 7.8	.78
Postoperative	50.4 ± 9.4	51.3 ± 8.3	.81
Last follow-up	50.8 ± 8.6	52.4 ± 8.1	.66
PT			
Preoperative	36.0 ± 10.5	38.3 ± 10.8	.62
Postoperative	24.3 ± 9.0	24.5 ± 7.8	.95
Last follow-up	23.6 ± 12.8	28.7 ± 8.2	.26
LL			
Preoperative	10.1 ± 21.1	9.4 ± 20.8	.94
Postoperative	40.2 ± 7.8	37.9 ± 20.0	.58
Last follow-up	38.8 ± 12.7	37.8 ± 13.3	.95
TK			
Preoperative	24.3 ± 12.5	32.1 ± 17.6	.25
Postoperative	34.2 ± 7.2	36.2 ± 12.1	.64
Last follow-up	37.7 ± 6.9	41.8 ± 17.7	.49
PI-LL			
Preoperative	40.4 ± 24.4	42.1 ± 20.7	.86
Postoperative	10.2 ± 12.0	13.4 ± 10.7	.51
Last follow-up	13.4 ± 14.6	12.0 ± 9.7	.79
SVA			
Preoperative	126.0 ± 58.4	140.3 ± 54.3	.56
Postoperative	36.1 ± 35.0	63.6 ± 42.2	.11
Last follow-up	68.0 ± 44.6	72.5 ± 70.1	.86
C7-CSVL			
Preoperative	25.3 ± 18.8	43.3 ± 32.7	.14
Postoperative	19.0 ± 11.6	19.8 ± 12.3	.87
Last follow-up	22.1 ± 18.4	16.7 ± 11.1	.42
L5-S1 angle			
Preoperative	8.7 ± 7.7	9.3 ± 6.6	.83
Postoperative	7.1 ± 4.1	7.8 ± 3.9	.64
Last follow-up	5.9 ± 5.5	5.4 ± 5.0	.83

Abbreviations: PI, pelvic incidence; PT, pelvic tilt; LL, lumbar lordosis; TK, thoracic kyphosis; SVA, sagittal vertical axis; CSVL, central sacral vertical line.

rate was 75.0%. Yasuda et al⁵ reported that 26.3% of patients with lower instrumented vertebrae without iliac screws required revision surgery for L5-S1 pseudarthrosis and instability; no patient with iliac screws required revision surgery for L5-S1 failure. Mazur et al¹⁹ evaluated 13 patients using S2AI screws and reported that 12 patients (92.3%) achieved an osseous L5-S1 fusion. Jain et al²⁰ also reported good results for the use of S2AI screws in ASD surgery to achieve lumbosacral fusion with no pseudarthrosis at the L5-S1 level with a minimum 5 years of follow-up. In our present study of S2 alar screws, patients in whom LL was less than ideal after surgery or patients with deterioration in SVA during their follow-up tend to be undercorrected, because of a smaller postoperative lordotic angle at the L5-S1 level, and decreasing L5-S1 lordosis at final follow-up. Although loosening of S2 alar screws did not directly affect recurrence of sagittal imbalance at the final follow-up, L5-S1 angle is significant higher just after surgery and at the final follow-up in patients with a PI-LL <10°. Moreover, the L5-S1 angle is significantly higher at final follow-up

in patients with an SVA increase <40 mm. These findings suggest that lumbar lordosis possibly decreases the reduction of the angle at L5-S1, and resulted in a PI-LL mismatch and SVA increase at the final follow-up. Patients with S2 alar screw loosening had a significantly lower BMI and a lower rate of fusion at L5-S1 than patients without screw loosening, suggesting screw loosening can result from poor bone quality, causing pseudoarthrosis at L5-S1. These findings indicate that fixation to the iliac bone might be advantageous in cases of osseous L5-S1 fusion for ASD.

Fixation, including that of the ilium, might achieve sufficient radiological correction in ASD surgery.²¹⁻²⁴ Kondo et al²² demonstrated using 60 patients with ASD that LL was obtained at a mean 50.4° from a preoperative 15.2° , suggesting fixation of the ilium is appropriate for achieving an ideal LL, which matches with their PI. Yasuda et al reported poorer clinical results and sagittal malalignment in patients with lower instrumented vertebra (LIV) at L5 or S1, than in those with iliac fixation, and recommended fusion to the ilium as LIV for long spinal fusion in patients with ASD.⁵ S2AI screws in ASD surgery are reported as useful for achieving lumbosacral fusion without pseudarthrosis at L5-S1.²⁰

ODI was significantly worse in patients with an SVA increase ≥ 40 mm than in those with an increase <40 mm at their final follow-up. The ODI score obtained at the final follow-up was significantly improved compared with the score obtained before surgery in patients with an SVA increase <40 mm, but did not improve in patients with an increase ≥ 40 mm, a finding consistent with previous reports that indicate a correlation between increased SVA and poor ODI score.²⁵⁻²⁷

There are several limitations to our present study. First, the study design was retrospective, without a control group, and the number of patients was small. Second, all the included findings had limited comparative data on the effects of S2 alar screws including several variations of surgical approaches, including osteotomy, OLIF, with or without L5-S1 interbody fusion, and the number of fused levels. However, because we used S2 alar screws for all of patients with ASD, the selection bias is relatively small. Third, a minimum 1-year follow-up is relatively short, but sufficient to show different outcomes. Further studies, including prospective comparative studies with a larger number of ASD patients, are needed to confirm whether S2 alar screws can be used safely.

Taken together, the findings from our radiological and clinical assessments indicate that benefits from the use of S2 alar screws in corrective surgery for ASD are limited. To warrant the use of S2 alar screws, patients should have a low PI without severe osteoporosis at baseline, and LL matched with PI should be achievable.



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