

# Failure of lumbopelvic fixation after long construct fusions in patients with adult spinal deformity: clinical and radiographic risk factors

## Clinical article

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**Object.** Lumbopelvic fixation provides biomechanical support to the base of the long constructs used for adult spinal deformity. However, the failure rate of the lumbopelvic fixation and its risk factors are not well known. The authors' objective was to report the failure rate and risk factors for lumbopelvic fixation in long instrumented spinal fusion constructs performed for adult spinal deformity.

**Methods.** This retrospective review included 190 patients with adult spinal deformity who had long construct instrumentation (> 6 levels) with iliac screws. Patients' clinical and radiographic data were analyzed. The patients were divided into 2 groups: a failure group and a nonfailure group. A minimum 2-year follow-up was required for inclusion in the nonfailure group. In the failure group, all patients were included in the study regardless of whether the failure occurred before or after 2 years. In both groups, the patients who needed a revision for causes other than lumbopelvic fixation (for example, proximal junctional kyphosis) were also excluded. Failures were defined as major and minor. Major failures included rod breakage between L-4 and S-1, failure of S-1 screws (breakage, halo formation, or pullout), and prominent iliac screws requiring removal. Minor failures included rod breakage between S-1 and iliac screws and failure of iliac screws. Minor failures did not require revision surgery. Multiple clinical and radiographic values were compared between major failures and nonfailures.

**Results.** Of 190 patients, 67 patients met inclusion criteria and were enrolled in the study. The overall failure rate was 34.3%; 8 patients had major failure (11.9%) and 15 had minor failure (22.4%). Major failure occurred at a statistically significant greater rate in patients who had undergone previous lumbar surgery, had greater pelvic incidence, and had poor restoration of lumbar lordosis and/or sagittal balance (that is, undercorrection). Patients with a greater number of comorbidities and preoperative coronal imbalance showed trends toward an increase in major failures, although these trends did not reach statistical significance. Age, sex, body mass index, smoking history, number of fusion segments, fusion grade, and several other radiographic values were not shown to be associated with an increased risk of major failure. Seventy percent of patients in the major failure group had anterior column support (anterior lumbar interbody fusion or transforaminal lumbar interbody fusion) while 80% of the nonfailure group had anterior column support.

**Conclusions.** The incidence of overall failure was 34.3%, and the incidence of clinically significant major failure of lumbopelvic fixation after long construct fusion for adult spinal deformity was 11.9%. Risk factors for major failures are a large pelvic incidence, revision surgery, and failure to restore lumbar lordosis and sagittal balance. Surgeons treating adult spinal deformity who use lumbopelvic fixation should pay special attention to restoring optimal sagittal alignment to prevent lumbopelvic fixation failure.

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**KEY WORDS** • adult • complication • deformity • iliac screws • instrumentation • pseudarthrosis • spine

*Abbreviations used in this paper:* ALIF = anterior lumbar interbody fusion; BMI = body mass index; CSVL = central sacral vertical line; ODI = Oswestry Disability Index; PI = pelvic incidence; PSIS = posterior superior iliac spine; PT = pelvic tilt; rhBMP = recombinant human bone morphogenetic protein; SRS = Scoliosis Research Society; SS = sacral slope; SVA = sagittal vertical axis; TLIF = transforaminal lumbar interbody fusion.

**R**IGID internal fixation of the spine can be an essential part of spine surgery in terms of maintaining deformity correction, providing stability to unstable segments, and promoting higher fusion rates.<sup>2</sup> For lumbosacral fusion, L5–S1 fixation alone is often insufficient in long constructs due to large cantilever forces above the base of the construct. Pelvic fixation may also

be considered for high-grade spondylolisthesis, unstable sacral fractures, or sacral tumors.<sup>6</sup> Various augmentations have been used to help protect S-1 screws such as the Galveston technique,<sup>1</sup> S-2 screws,<sup>13</sup> the 4-rod technique,<sup>17</sup> S-2 alar iliac screws,<sup>11</sup> and a combination of S-1 and iliac screws (S1–iliac screws).<sup>3</sup> Among these, S1–iliac screws remain the most commonly used.

Constructs using S1–iliac screws have been shown to enhance fusion rates across the L5–S1 level.<sup>8</sup> In a long-term study with a minimum 5-year follow-up, 5 cases of lumbosacral nonunion were reported in 67 cases with S1–iliac screws; 23 of these cases ultimately required removal of the iliac screws.<sup>18</sup> However, both spondylolisthesis and long lumbosacral constructs were included in this study, and the authors did not provide an assessment of risk factors for failure.

The purpose of the present study is to report the failure rate and risk factors for failure of lumbopelvic fixation with S1–iliac screws used at the base of long constructs in patients with adult spinal deformity.

## Methods

This study was a retrospective review of consecutive patients with adult spinal deformity whom we treated surgically at the University of Virginia Health System between 2004 and 2010. Inclusion criteria were an age of 18 years or older, thoracolumbar spinal deformity treated surgically with posterior instrumentation that included iliac screws, and instrumentation of more than 6 spinal levels. In addition, inclusion required demonstration of lumbopelvic fixation failure or a minimum 2-year follow-up in cases without lumbopelvic fixation failure. Patients who required a revision for causes other than lumbopelvic fixation failure (for example, proximal junctional kyphosis) were excluded. This study was approved by the institutional review board of the University of Virginia.

Clinical and radiographic data were extracted from outpatient and hospital records. Patients were divided into 2 groups, a failure group and a nonfailure group, based on the occurrence of lumbopelvic fixation failure. Failures were defined as major or minor. Major failures included rod breakage between L-4 and S-1, failure of S-1 screws (breakage, halo formation, or pullout), and prominent iliac screws requiring removal (Fig. 1). Minor failures did not require surgical revision and included rod breakage between S-1 and iliac screws and failure of iliac screws (Fig. 2). For the 3 groups (major failure, minor failure, and nonfailure), improvement in SRS score and ODI was compared between preoperative and final follow-up time points.

Iliac screws were placed as previously described.<sup>3</sup> In brief, an osteotome was used to remove an approximately 3- to 5-cm wedge of bone from the medial wall of the PSIS. An iliac “gear shift” was used to develop the trajectory. Inlet and outlet fluoroscopy views were used to confirm the appropriate trajectory based on the “tear drop” and the sciatic notch. A tap was used to prepare the trajectory, followed by screw placement. A ball-tip probe was used to assess the trajectory after using the “gear shift” and the tap. Iliac screw heads were recessed into

the PSIS at a level to be flush with the lateral wall of the PSIS. Lateral connectors were typically used to facilitate connection of the iliac screws to the rod construct.

Multiple clinical, operative, and radiographic parameters were compared between the major failure and nonfailure groups. Clinical and operative data compared included age, BMI, number of comorbidities, history of previous thoracolumbar spine surgery, diameter and length of iliac screws, and the type and amount of bone grafting material and rhBMP-2 used. Radiographic data included preoperative and postoperative values and the change in these values (postoperative – preoperative) for the following: lumbar lordosis (sagittal Cobb angle between the inferior endplate of T-12 and the superior endplate of S-1), PT, SS, SVA (the horizontal distance between the C-7 plumb line and the posterosuperior aspect of the sacrum), and coronal alignment (the horizontal distance between the C-7 plumb line and the CSVL). Radiographic measures were obtained as previously described.<sup>14</sup>

Fusion status at the level of L4–S1 was compared between major failure and nonfailure groups. A modified version of the Lenke fusion grading system,<sup>10</sup> using Grades A to F, was applied to posterior arthrodesis procedures, with Grade A representing bilateral solid fusion masses and Grade F representing minimal to no bony fusion mass bilaterally (Fig. 3). Those with Grade C and above fusions were considered to have undergone successful posterior fusions. For anterior arthrodesis procedures (ALIF or TLIF), the presence of a sentinel sign<sup>4,12</sup> at the disc space level was considered successful anterior fusion. If there was no sentinel sign or no interbody arthrodesis procedure was performed (either ALIF or TLIF), the interbody space was considered to have anterior nonfusion. A vertebral level was considered to be fused if the level demonstrated interbody and/or posterior fusion. Two independent surgeons graded the fusion status, and interobserver reliability was acceptable ( $\kappa > 0.714$ , agreement 87.5%).

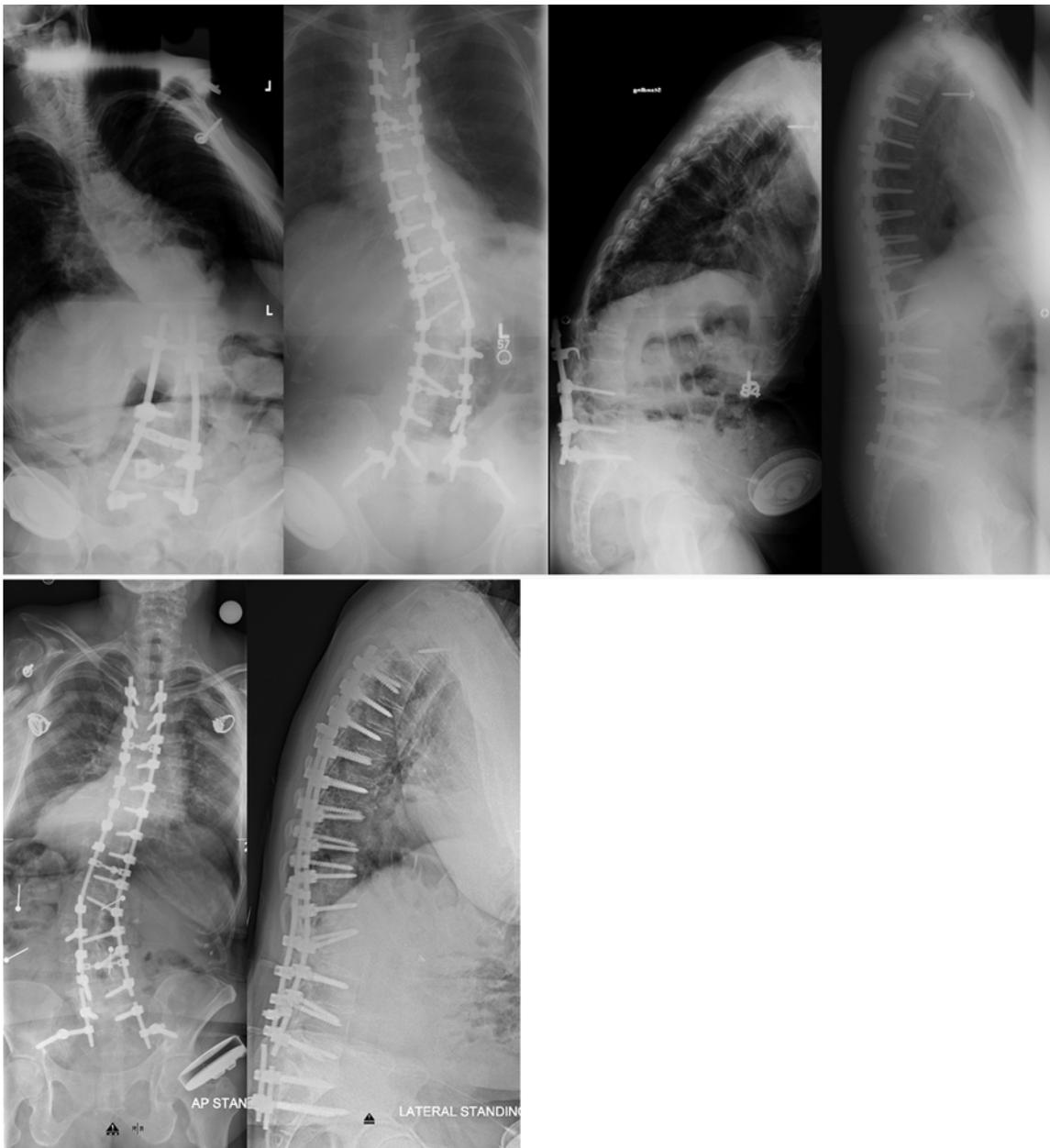
Statistical comparisons were made between major failure and nonfailure groups using a 2-tailed t-test or Fisher exact test depending on the number of subjects in each category. A p value < 0.05 was considered statistically significant.

## Results

Of 190 patients with adult spinal deformity who were reviewed, 67 met inclusion criteria and were assessed in the present study. The study population included 51 women and 16 men, and the overall mean patient age was  $64.9 \pm 11.1$  years (range 23–84 years). The mean number of vertebral levels fused was  $8.6 \pm 2.6$ . A total of 23 patients (34.3%) demonstrated lumbopelvic fixation failure, including 8 patients (11.9%) with major failure and 15 patients (22.4%) with minor failure. The mean time to major failure was 3.5 years (range 0.5–6.3 years), and the mean length of follow-up for the nonfailure group was 3.0 years (range 1.9–5.0 years).

Clinical and radiographic data were compared between the major failure and nonfailure groups (Table 1). Compared with the nonfailure group, patients in the ma-

## Failure of lumbopelvic fixation

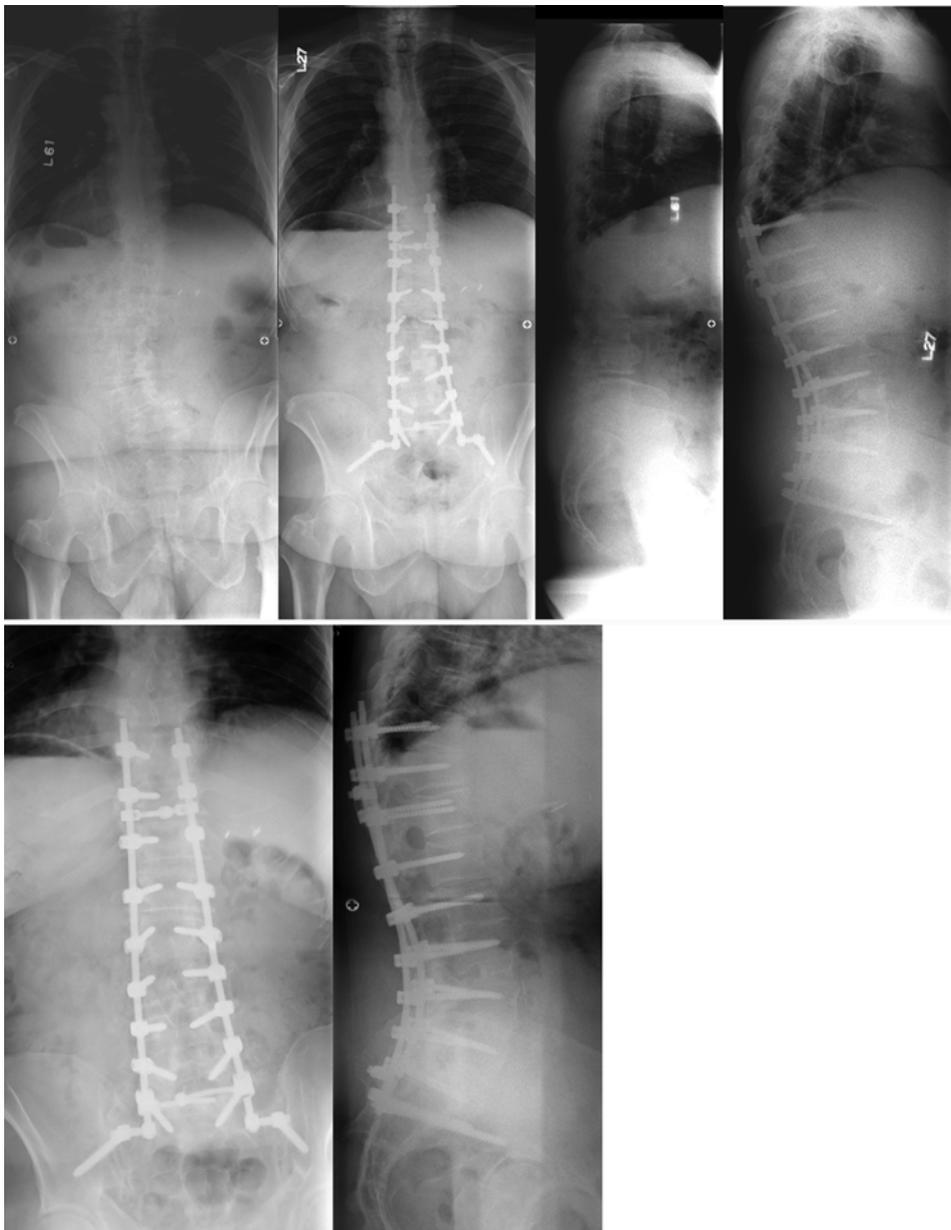


**Fig. 1. Upper:** Preoperative and postoperative radiographs obtained in a patient in the major failure group. **Lower:** The bilateral rod breakage at the L5–S1 level is considered a major failure because it required a revision surgery due to pseudarthrosis.

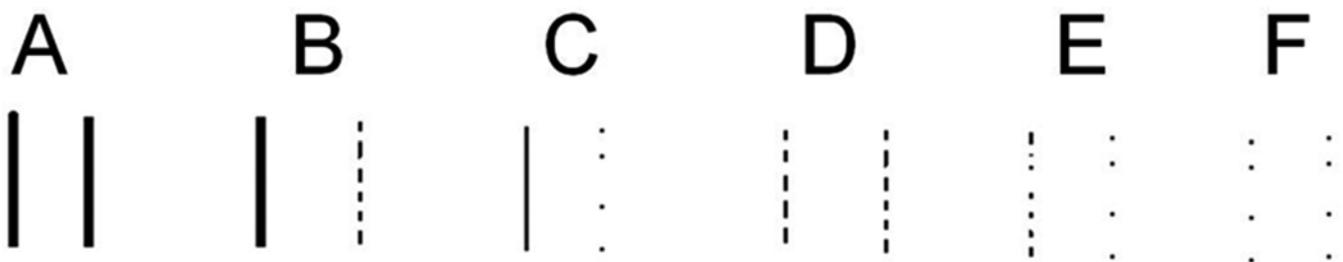
major failure group had a significantly higher rate of previous surgery (75% vs 32%,  $p = 0.043$ ), greater PI (72.1° vs 62.7°,  $p = 0.015$ ), less postoperative lumbar lordosis (−46.0° vs 53.1°,  $p = 0.033$ ), a trend toward poorer postoperative SVA (70.3 mm vs 49.6 mm,  $p = 0.05$ ), and a trend toward a greater mean number of comorbidities (4.0 vs 3.3,  $p = 0.061$ ). The groups did not differ significantly with regard to age, BMI, number of comorbidities, number of levels fused, smoking status, diameter and length of iliac screws placed, or PT parameters ( $p > 0.05$ ; Table 1). When the 3 groups (major failure, minor failure, and nonfailure) were compared in terms of improvement in SRS score and ODI between preoperative and final follow-up, patients with major failures did not show a sta-

tistically significant difference regarding SRS score or ODI ( $p = 0.536$ ). Patients with minor failures did show a statistically significant improvement in both scores when preoperative scores were compared with those obtained at 2-year follow-up. The SRS score increased from 2.33 to 3.23 ( $p = 0.013$ ), and the ODI improved from 26.4 to 13 ( $p = 0.02$ ). A 1-way ANOVA test showed a statistically significant difference between the groups regarding the postoperative ODI ( $p = 0.001$ ). The nonfailure group also showed a similar statistically significant increase in SRS scores (from 2.4 to 3.0,  $p = 0.001$ ) and improvement in ODI (from 29.2 to 23.9,  $p = 0.013$ ) (Table 2).

The number of cases demonstrating radiographic fusion (Grade C and above) for the major failure and non-



**FIG. 2. Upper:** Preoperative and postoperative radiographs obtained in a patient in the minor failure group. **Lower:** The unilateral rod breakage below the S-1 level was classified as a minor failure because it did not require a revision surgery and likely reflects expected continued motion at the sacroiliac joint after solid fusion at L5–S1.



**FIG. 3.** A modified Lenke fusion grading system was used for posterior fusion, and Grades A to F were used as shown here. Fusions of Grade C and higher were considered successful posterior fusions.

## Failure of lumbopelvic fixation

**TABLE 1: Major failure versus nonfailure**

Data	Group*		p Value†
	Major Failure (n = 8)	Nonfailure (n = 44)	
<b>Clinical</b>			
mean age (yrs)	66.98 ± 8.89	65.72 ± 9.68	0.723
mean BMI	30.11 ± 7.33	28.93 ± 7.14	0.684
mean no. of comorbidities	4 ± 0.76	3.3 ± 1.47	0.061
no. of smokers	0 (0)	2 (5)	1.000 (Fisher exact test)
mean no. of levels fused	9 ± 4.11	8.32 ± 3.20	0.668
no. of patients w/ revision surgery	6 (75)	14 (32)	<b>0.043 (Fisher exact test)</b>
mean iliac screw diameter (mm)	7.65 ± 0.47	7.72 ± 0.46	0.45
mean iliac screw length (mm)	79.13 ± 4.98	76.82 ± 9.01	0.11
<b>Radiographic</b>			
mean PI (°)	72.1 ± 9.70	62.7 ± 7.93	<b>0.015</b>
mean preop PT (°)	34.9 ± 13.4	28.1 ± 7.33	0.106
mean postop PT (°)	34.5 ± 15.3	26.9 ± 6.67	0.106
mean change in PT (°)	-0.4 ± 1.9	-1.22 ± 0.66	0.838
mean preop SS (°)	37.3 ± 10.8	34.59 ± 8.19	0.529
mean postop SS (°)	34.00 ± 6.37	36.14 ± 9.61	0.451
mean preop SVA (mm)	136 ± 50	101 ± 27	0.557
mean postop SVA (mm)	70.3 ± 18.8	49.6 ± 41.1	<b>0.05</b>
mean preop C-7 to CSVL (absolute value)	49.1 ± 27.1	24.8 ± 17.9	0.057
mean postop C-7 to CSVL (absolute value)	26.6 ± 12	27.4 ± 3.3	0.951
mean change in C-7 to CSVL (absolute value)	33.4 ± 7.7	18.4 ± 2.6	0.106
mean preop lordosis (°)	-27.0 ± 23.5	-34.8 ± 19.3	0.404
mean postop lordosis (°)	-46 ± 7.09	-53.08 ± 9.74	<b>0.033</b>
mean change in lordosis (°)	-19 ± 20.0	-18.3 ± 15.9	0.927
mean postop lordosis + PI (mismatch) (°)	35.29 ± 17.27	8.82 ± 13.70	<b>&lt;0.005</b>

\* Mean values are presented as the mean ± SD. Other values indicate the number of patients (%).

† The t-test was used for all categories except where indicated. Values in boldface are statistically significant.

failure groups are summarized and compared in Table 3. The number of cases demonstrating radiographic fusion did not differ significantly between the major failure and nonfailure groups based on assessment of posterior fusion (5 of 8 vs 27 of 44, respectively), anterior fusion (4 of 8 vs 19 of 44, respectively), and total fusion (6 of 8 vs 33 of 44).

The types and amount of graft material used in each case are summarized in Table 4. All patients received locally harvested autogenous bone graft, and rhBMP-2 was used in the vast majority of patients. Seventy percent of patients in the major failure group had anterior column support (ALIF or TLIF) at the lower lumbar level(s),

while 80% of patients in the nonfailure group had anterior column support (p = 0.37).

### Discussion

Pelvic fixation provides biomechanical support to the base of the long constructs used for adult spinal deformity, with the objective of promoting higher fusion rates. Various supplemental fixation methods have been proposed, including the Galveston technique,<sup>1</sup> S-2 screws,<sup>13</sup> the 4-rod technique,<sup>17</sup> S-2 alar iliac screws,<sup>11</sup> and S1-iliac screws.<sup>3</sup> Among these, the S1-iliac screw approach with or without anterior column support has been reported to

**TABLE 2: Subgroup analysis among major failure, minor failure, and nonfailure groups**

Group	SRS Score			ODI		
	Preop	Final Follow-Up	p Value (paired t-test)	Preop	Final Follow-Up	p Value (paired t-test)
major failure	2.73 ± 0.81	3 ± 0.16	0.54	24.25 ± 9.98	24.75 ± 3.40	0.92
minor failure	2.33 ± 0.58	3.23 ± 0.71	0.01	26.4 ± 3.21	13 ± 7.75	0.02
nonfailure	2.4 ± 0.55	2.96 ± 0.57	0.00	29.2 ± 6.18	23.9 ± 4.79	0.01

TABLE 3: Fusion rate at L4–S1 in the major failure group versus the nonfailure group

Parameter	No. of Radiographic Fusions Grade C & Above (%)		p Value (Fisher exact test)
	Major Failure (n = 8)	Nonfailure (n = 44)	
posterior fusion achieved	5 (62)	27 (61)	0.672
anterior fusion achieved	4 (50)	19 (43)	1.000
total fusion achieved	6 (75)	33 (75)	0.286

be biomechanically the strongest,<sup>5,9</sup> and it is considered one of the current standards for fixation of the lumbosacral spine in the setting of long constructs.

Kuklo et al. reported a 95.1% lumbosacral fusion rate using S1–iliac screw fixation at the base of long constructs.<sup>8</sup> Tsuchiya et al. studied 67 patients with lumbosacral fusions using an S1–iliac screw construct and reported 5 cases of lumbosacral nonunion.<sup>18</sup> In their study, iliac screws were removed in 23 cases. The authors reported no evidence of loosening, pullout, or breakage of the S-1 screws, but they did report 7 cases of iliac screw failure and 29 cases of iliac screw halo formation. However, their study included both spondylolisthesis and long lumbosacral constructs, and it did not report the risk factors for failure. The present study provides lumbopelvic fixation failure rates specifically for long constructs used in adult spinal deformity correction, and it also provides assessment of risk factors for these failures.

There is no consensus on the definition of failure of lumbopelvic fixation. Construct failure above the S-1 screws (L-5 to S-1) is generally considered a failure of lumbopelvic fixation. However, failure below the S-1 screws (failure of the rod between the S-1 and iliac screws or haloing of the iliac screws) is not necessarily failure of lumbopelvic fixation, especially if it occurs following achievement of successful L5–S1 fusion. In the present series, no lumbopelvic fixation revisions were required when the failure in the construct was below the S-1 screws. Therefore, we classified the failures of lumbopelvic fixation into major and minor groups. Major failure included rod breakage between L-4 and S-1, failure of the S-1 screws (breakage, halo formation, or pullout), and prominent iliac screws requiring removal. Minor failure included rod breakage between the S-1 and iliac screws and failure of iliac screws. The results of subgroup analysis among major failures, minor failures, and nonfailures validated the definition of lumbopelvic fixation failure. Minor failure (haloing or breakage around the pelvic fixation) is not clinically significant, but major failure does affect clinical outcomes.

All iliac screw–related problems (breakage or halo formation) were considered minor failures except when there was clinically significant prominence of the iliac screws. Halo formation around the iliac screw may be a favorable sign rather than a complication. Tumialán et al. advocated that a halo around an iliac screw can be a sign of stress shielding of an S-1 screw.<sup>19</sup> In this study, there were 5 cases of halo formation around iliac screws. As the number was so small, no comparison was made between the halo around iliac screws and other failures. However, a halo around an iliac screw was included in the minor failure group and showed significant clinical im-

provement between preoperative and final follow-up time points. Prominence of iliac screws was considered a major failure when prominent screws resulted in symptoms severe enough to require removal. O'Shaughnessy et al. reported a removal rate of 6.1% due to iliac screw prominence.<sup>15</sup> After removal of the prominent iliac screws, 87% of the patients reported an improvement in their symptoms. In our study, 3.0% of cases required removal of prominent iliac screws, and these cases were included in the major failure group. The relatively low rate of iliac screw prominence requiring removal in the present series may be related to the technique used, in which the heads of iliac screws are recessed into the PSIS.

The incidence of overall lumbopelvic fixation failure in the present series was 34.3%, and the incidence of clinically significant major failure was 11.9%. The minor failures (rate of 22.4%) were primarily related to the mobile sacroiliac joint, which does not necessarily cause the adverse outcome as it can be caused by the solid fusion at L4–S1. However, even when the major failure group was compared with the nonfailure group in terms of fusion, there was a tendency for more fusion in the nonfailure group, but there was no significant difference even after the fusion status was graded by 2 independent observers with high interobserver reliability (Table 2). Therefore, we can deduce that some other risk factors, aside from fusion, play a prominent role in lumbopelvic fixation failure.

Risk factors for major failures are a larger PI, revision surgery, and failure to restore lumbar lordosis and sagittal balance. Interestingly, 70% of patients in the major failure group had anterior column support (ALIF or TLIF) at the lower lumbar level(s), while 80% of patients in the nonfailure group had anterior column support, which was not significantly different even though there were more cases with anterior support in the nonfailure group. Theoretically, addition of anterior column support at the bottom of the long construct should prevent lumbopelvic fixation failure even though the findings were not significantly different in our study. Therefore, the effect of anterior column support on the long construct with pelvic fixation needs to be studied further with a larger number of failure cases. Most of the risk factors identified are related to failure of restoring proper sagittal alignment. Larger preoperative PI requires a greater correction to postoperative lumbar lordosis,<sup>16</sup> and less lumbar lordosis will cause less optimal sagittal alignment.<sup>7</sup> When the postoperative lumbar lordosis/PI mismatch was compared between the major failure and nonfailure groups, there was a significant difference in our study as shown in Table 1 ( $p < 0.005$ ). Improperly restored sagittal alignment may predispose to more biomechanical stress on lumbopelvic fixation, resulting in a higher failure rate. Therefore, surgeons treat-

## Failure of lumbopelvic fixation

**TABLE 4: Number of fusion levels, type of fusion, and total amount of graft material used for each patient\***

Case No.	No. w/ PSF	ASF (L4–5)	ASF (L5–S1)	No. of rhBMP-2 Kits & Size†	Total Allograft (cm <sup>3</sup> )	Autograft (AIBG or local)
<b>Failure Group (major &amp; minor)</b>						
1	8	no	yes	1 large	0	yes
2	7	yes	yes	4 large	0	yes
3	16	yes	yes	2 large	0	yes
4	8	no	no	0	0	yes
5	7	no	yes	0	0	yes
6	8	no	yes	0	30	yes
7	16	no	no	0	30	yes
8	8	yes	no	0	30	yes
9	7	yes	yes	2 large	30	yes
10	7	yes	no	1 small	30	yes
11	8	no	no	2 large	0	yes
12	7	no	no	1 large	0	yes
13	8	no	yes	1 large	60	yes
14	8	no	no	2 large	60	yes
15	8	yes	yes	1 large	60	yes
16	8	yes	yes	1 large	0	yes
17	8	no	yes	2 large	0	yes
18	8	yes	yes	6 large	30	yes
19	7	yes	yes	2 large	30	yes
20	14	no	yes	3 large	30	yes
21	7	no	no	3 large	60	yes
22	8	no	no	3 large	30	yes
23	16	yes	yes	3 large	60	yes
<b>Nonfailure Group</b>						
1	8	no	no	0	60	yes
2	14	no	no	0	90	yes
3	6	yes	yes	1 large	femoral ring (interbody)	yes
4	6	no	no	1 large	60	yes
5	8	no	no	0	0	yes
6	14	yes	yes	0	femoral ring (interbody)	yes
7	14	yes	yes	1 small	60	yes
8	8	yes	no	1 large	30	yes
9	8	yes	yes	2 large	30	yes
10	8	yes	yes	2 large	30	yes
11	13	yes	yes	4 large	90	yes
12	7	yes	no	2 large	30	yes
13	13	no	yes	2 large	60	yes
14	9	yes	yes	2 large	60	yes
15	7	yes	yes	2 large	60	yes
16	6	yes	no	1 large	0	yes
17	8	yes	yes	2 large	60	yes
18	8	yes	yes	2 large	90	yes
19	6	yes	yes	2 large	30	yes
20	8	yes	yes	2 large	0	yes
21	8	no	yes	3 large	90	yes
22	8	yes	yes	3 large	120	yes

(continued)

TABLE 4: Number of fusion levels, type of fusion, and total amount of graft material used for each patient\* (continued)

Case No.	No. w/ PSF	ASF (L4–5)	ASF (L5–S1)	No. of rhBMP-2 Kits & Size†	Total Allograft (cm <sup>3</sup> )	Autograft (AIBG or local)
Nonfailure Group (continued)						
23	14	no	no	4 large	180	yes
24	7	yes	no	2 large	90	yes
25	8	yes	yes	3 large	90	yes
26	7	yes	no	3 large	30	yes
27	6	no	no	3 large	30	yes
28	8	yes	yes	3 large	60	yes
29	9	yes	yes	4 large	90	yes
30	8	no	no	3 large	0	yes
31	8	yes	yes	3 large	60	yes
32	9	no	no	3 large	60	yes
33	7	yes	no	3 large	60	yes
34	8	yes	yes	3 large	90	yes
35	8	yes	yes	3 large	90	yes
36	6	yes	yes	2 large	30	yes
37	7	no	yes	2 large	60	yes
38	7	yes	yes	3 large	90	yes
39	8	no	yes	3 large	90	yes
40	8	no	yes	4 large	20	yes
41	6	yes	yes	3 large	90	yes
42	7	yes	yes	3 large	60	yes
43	7	no	no	3 large	60	yes
44	8	no	yes	2 large	60	yes

\* AIBG = autogenous iliac bone graft; ASF = anterior screw fixation; PSF = posterior screw fixation.

† A small kit of rhBMP-2 is 4.2 mg and a large kit is 12 mg.

ing adult spinal deformity who use lumbopelvic fixation for long construct fusions should pay special attention to restoring optimal sagittal alignment to prevent lumbopelvic fixation failure.

### Conclusions

The incidence of overall failure was 34.3%, and the incidence of clinically significant major failure after lumbopelvic fixation after long construct fusion in adult spinal deformity surgery was 11.9%. Risk factors for major failures are a larger PI, revision surgery, and failure to restore lumbar lordosis and sagittal balance.

### Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Cho, Arlet. Acquisition of data: Cho, Mason, Wilson. Analysis and interpretation of data: Cho, Mason. Drafting the article: Cho, Shimer, Fu, Heller. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Cho. Statistical analysis: Mason, Novicoff. Administrative/technical/material sup-

port: Shimer, Shaffrey, Shen, Arlet. Study supervision: Shaffrey, Shen, Arlet.

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