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## Operative Treatment of Severe Scoliosis in Symptomatic Adults: Multicenter Assessment of Outcomes and Complications With Minimum 2-Year Follow-up

**BACKGROUND:** Few reports focus on adults with severe scoliosis.

**OBJECTIVE:** To report surgical outcomes and complications for adults with severe scoliosis.

**METHODS:** A multicenter, retrospective review was performed on operatively treated adults with severe scoliosis (minimum coronal Cobb: thoracic [TH]  $\geq 75^\circ$ , thoracolumbar [TL]  $\geq 50^\circ$ , lumbar [L]  $\geq 50^\circ$ ).

**RESULTS:** Of 178 consecutive patients, 146 (82%; TH = 8, TL = 88, L = 50) achieved minimum 2-yr follow-up (mean age =  $53.9 \pm 13.2$  yr, 92% women). Operative details included posterior-only (58%), 3-column osteotomy (14%), iliac fixation (72%), and mean posterior fusion =  $13.2 \pm 3.7$  levels. Global coronal alignment (3.8 to 2.8 cm,  $P = .001$ ) and maximum coronal Cobb improved significantly ( $P \leq .020$ ): TH ( $84^\circ$  to  $57^\circ$ ; correction = 32%), TL ( $67^\circ$  to  $35^\circ$ ; correction = 48%), L ( $61^\circ$  to  $29^\circ$ ; correction = 53%). Sagittal alignment improved significantly ( $P < .001$ ), most notably for L: C7-sagittal vertical axis 6.7 to 2.5 cm, pelvic incidence-lumbar lordosis mismatch  $18^\circ$  to  $3^\circ$ . Health-related quality-of-life (HRQL) improved significantly ( $P < .001$ ), most notably for L: Oswestry Disability Index ( $44.4 \pm 20.5$  to  $26.1 \pm 18.3$ ), Short Form-36 Physical Component Summary ( $30.2 \pm 10.8$  to  $39.9 \pm 9.8$ ), and Scoliosis Research Society-22r Total ( $2.9 \pm 0.7$  to  $3.8 \pm 0.7$ ). Minimal clinically important difference and substantial clinical benefit thresholds were achieved in 36% to 75% and 29% to 51%, respectively. Ninety-four (64%) patients had  $\geq 1$  complication (total = 191, 92 minor/99 major, most common = rod fracture [13.0%]). Fifty-seven reoperations were performed in 37 (25.3%) patients, with most common indications deep wound infection (11) and rod fracture (10).

**CONCLUSION:** Although results demonstrated high rates of complications, operative treatment of adults with severe scoliosis was associated with significant improvements in mean HRQL outcome measures for the study cohort at minimum 2-yr follow-up.

**KEY WORDS:** Adult spinal deformity, Complications, Coronal imbalance/malalignment, Health-related quality of life, Outcomes, Sagittal imbalance/malalignment, Scoliosis, Spine surgery

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In appropriately selected patients, operative management of adult spinal deformity (ASD) can lead to significant improvement

in pain, disability, and health-related quality of life (HRQL).<sup>1,2</sup> Despite these benefits, ASD surgery is associated with high complication

**ABBREVIATIONS:** ASD, adult spinal deformity; ASLS-1, Adult Symptomatic Lumbar Scoliosis-1; GCM, global coronal malalignment; HRQL, health-related quality of life; ISSG, International Spine Study Group; LL, lumbar lordosis; MCID, minimum clinically important difference; MCS, Mental Component Summary; NRS, Numerical Rating Scale; ODI, Oswestry Disability Index; PCS, Physical Component Summary; PI, pelvic incidence; PI-LL, mismatch between PI and LL; PT, pelvic tilt; SCB, substantial clinical benefit; SF-36, Short Form-36; SRS, Scoliosis Research Society; SVA, sagittal vertical axis; TK, thoracic kyphosis; 3CO, 3-column osteotomy

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rates.<sup>3-5</sup> When complications occur, there can be reduced potential for meaningful clinical improvement, and in some cases, revision operations may be warranted.<sup>3-6</sup> As such, substantial research has focused on preventing complications and reducing their potential negative impact.<sup>7-13</sup> To design effective complication-prevention strategies, high-quality outcome studies with accurate and detailed complication risk profiles are needed. Such studies provide benchmark data to facilitate focused research efforts, and in addition, can improve patient counseling regarding risk-benefit assessment and appropriate clinical expectations.

High-quality, multicenter studies have demonstrated efficacy for operative management of symptomatic ASD, but few focused on the subset of ASD characterized by severe scoliosis.<sup>1,14-16</sup> Previous studies generally involved ASD with mild and/or moderate curves, and current outcomes data for severe adult scoliosis surgery are limited to small, single-center studies.<sup>17</sup> Therefore, our objective was to perform a multicenter prospective assessment of surgical outcomes and complications in the subset of ASD patients with severe scoliosis. We hypothesized that surgical treatment of severe adult scoliosis was associated with significant HRQL improvement despite high associated complication rates.

## METHODS

### Patient Selection

This is a retrospective analysis of prospectively collected data from consecutive ASD patients enrolled at multiple institutional review board-approved centers across the United States. Dates of enrollment were January 2008 to April 2015. Database enrollment required patient age  $\geq 18$  yr and  $\geq 1$  of the following: scoliosis  $\geq 20^\circ$ , C7-S1 sagittal vertical axis (SVA)  $\geq 5$  cm, pelvic tilt (PT)  $\geq 25^\circ$ , or thoracic kyphosis (TK)  $\geq 60^\circ$ . Patients with active infection, malignancy, or nonidiopathic/degenerative scoliosis were excluded. We focused on operatively treated patients with severe scoliosis, defined by the major curve magnitude and apex as follows: thoracic (TH) Cobb  $\geq 75^\circ$  (apex T2 to

T8-9), thoracolumbar (TL) Cobb  $\geq 50^\circ$  (apex T8-9 to L1-2), and lumbar (L) Cobb  $\geq 50^\circ$  (apex L1-2 to L4)<sup>17-19</sup> (Figure 1). Management decisions were determined by the consent process between patient and surgeon. If surgery was pursued, further treatment details, such as approach and osteotomies, were also based on the consent process between patient and surgeon.

### Data Collection, Radiographic Assessment, and HRQL

Data were extracted from standardized sheets, and included demographics, Charlson Comorbidity Index<sup>20</sup> and ASD-Frailty Index.<sup>21</sup> Full-length 36-inch long cassette spinal radiographs were obtained and analyzed with validated software (Spineview; ENSAM Laboratory of Biomechanics).<sup>22,23</sup> All radiographic calculations were performed using standard technique,<sup>24</sup> and included global coronal malalignment (GCM), pelvic obliquity, scoliosis Cobb angles, C7-S1 SVA, PT, lumbar lordosis (LL, T12-S1), mismatch between pelvic incidence (PI) and LL (PI-LL), and TK (T4-T12). HRQL were prospectively collected: Oswestry Disability Index (ODI),<sup>25,26</sup> Short Form (SF)-36 (Physical Component Summary [PCS] and Mental Component Summary [MCS]),<sup>27</sup> Scoliosis Research Society (SRS)-22r,<sup>28,29</sup> and Numerical Rating Scale (NRS) for back/leg pain (no pain = 0, maximum pain = 10). Differences in HRQL were evaluated according to previously reported values of minimal clinically important difference (MCID) and substantial clinical benefit (SCB).<sup>30-32</sup>

### Assessment of Complications

Accuracy and completeness of complication collection was facilitated by use of standardized forms, onsite coordinators, and regular audits performed at a central location. Complications were classified as minor/major per Smith and colleagues.<sup>3,5</sup> Assessment of timing of complications was also performed: intraoperative, early ( $<30$  d postop) or delayed ( $>30$  d postop). Complications were also collected and analyzed for eligible patients who did not achieve minimum 2-yr follow-up to assess the potential bias from loss of follow-up.

### Statistical Analysis

Data were summarized using means and standard deviations for continuous variables, and frequencies with percentages for categorical variables. Normality of continuous data was assessed using the Shapiro-Wilk test. Comparison of scoliosis subgroups (TH vs TL vs L) was performed using the Kruskal-Wallis test, 1-way analysis of variance, Mann-Whitney *U* test, independent *t*-test, Fisher's exact test, and Chi-squared test. Post hoc analyses with Bonferroni-corrected multiple pairwise comparisons were performed. The Wilcoxon signed-rank test or paired *t*-test or were used for assessment of repeated measurements. Statistical analyses were performed using Statistical Package for Social Science version 26.0 (IBM SPSS Statistics for Windows, Version 26.0, Armonk, New York). All tests were 2-tailed and *P*-values  $< .05$  were considered statistically significant. The Strengthening the Reporting of Observational studies in Epidemiology guidelines were followed when reporting study findings.

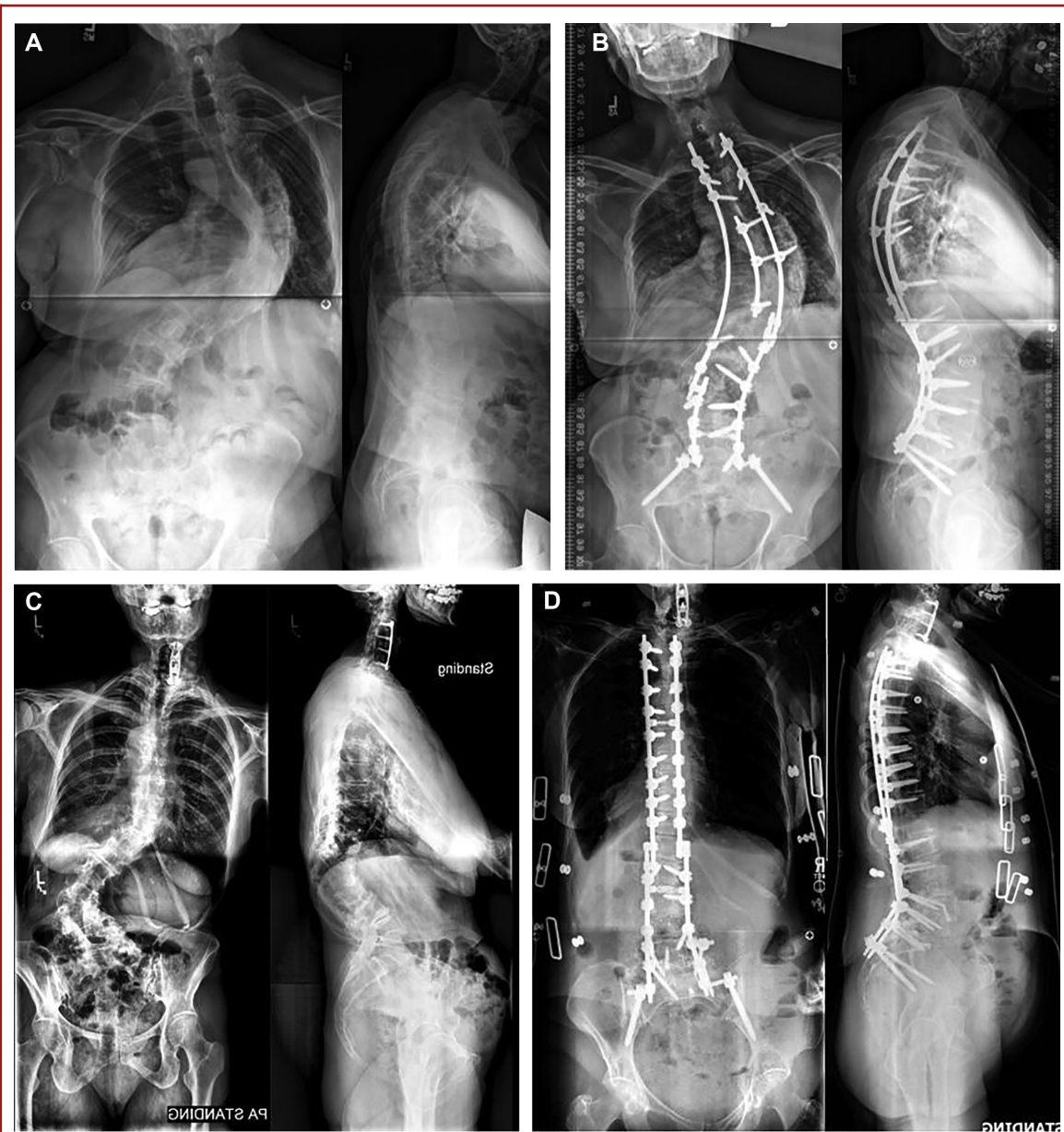
## RESULTS

### Study Cohort and Baseline Characteristics

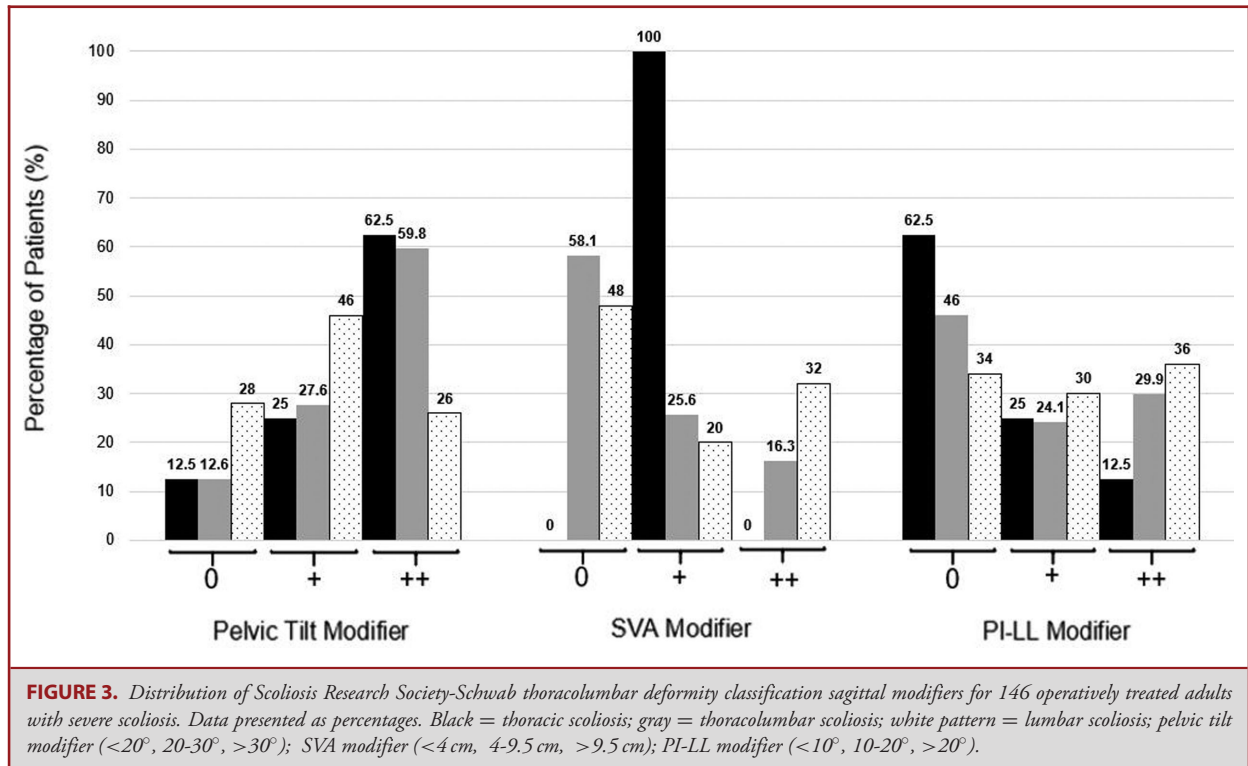
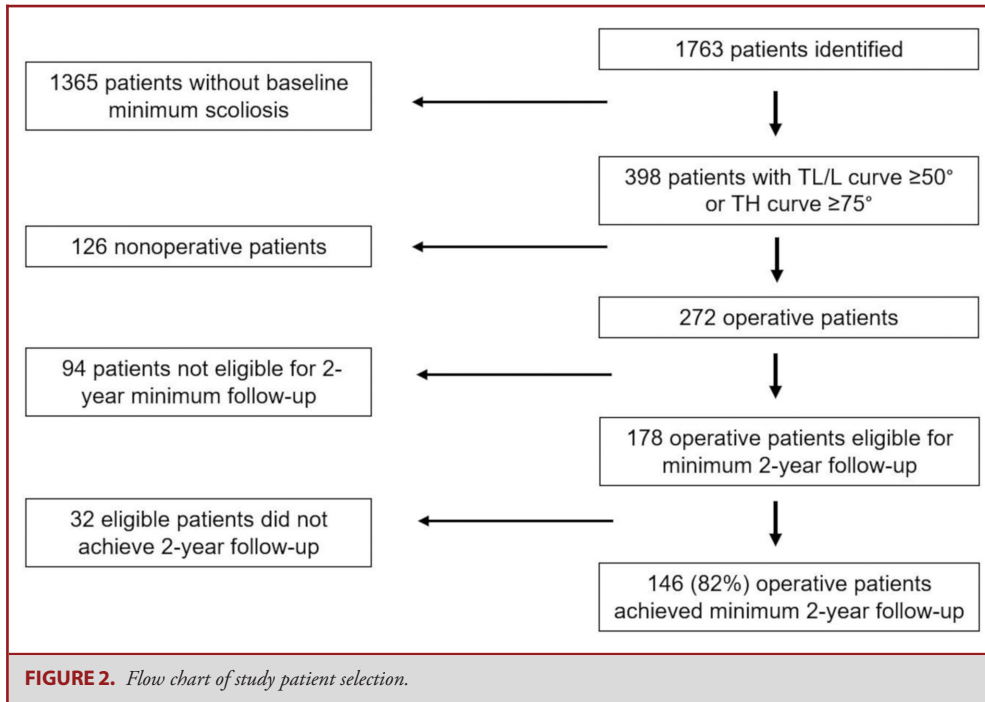
At the time of data extraction, there were 178 ASD patients who met inclusion criteria for severe scoliosis and had

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**FIGURE 1.** Preoperative **A** and postoperative **B** standing radiographs of a study subject with severe thoracic scoliosis (baseline thoracic curve magnitude  $86.9^\circ$  and global coronal malalignment 5.3 cm). Preoperative HRQL measures were ODI 42, PCS 27, MCS 42, SRS-22r total 2.9, activity 3.2, pain 3.0, appearance 2.0, mental 3.8, and satisfaction 1.5. There were no operative complications requiring revision surgery. Last HRQL measures were ODI 40, PCS 35, MCS 29, SRS-22r total 3.1, activity 3.0, pain 3.6, appearance 2.8, mental 2.8, and satisfaction 4.0. Next, preoperative **C** and postoperative **D** standing radiographs are presented for a different study subject with severe lumbar scoliosis (baseline lumbar curve magnitude  $64.0^\circ$  and global coronal malalignment 13.6 cm). Preoperative HRQL measures were ODI 24, PCS 47, MCS 64, SRS-22r total 3.7, activity 4.2, pain 2.6, appearance 2.8, mental 5.0, and satisfaction 4.5. There was an operative radiographic complication (proximal junctional kyphosis/failure) requiring revision surgery. Last HRQL measures were ODI 20, PCS 45, MCS 60, SRS-22r total 4.0, activity 4.0, pain 3.4, appearance 4.2, mental 5.0, and satisfaction 3.0.



**TABLE 1. Baseline Demographics and Comorbidities for 146 Operatively Treated Adults With Severe Scoliosis<sup>a</sup>**

Parameter	Comparison of scoliosis subtypes				<sup>c</sup> P-value <sup>d</sup> P, <sup>e</sup> P, <sup>f</sup> P
	All (n = 146)	Thoracic (n = 8)	Thoracolumbar (n = 88)	Lumbar (n = 50)	
Age at index surgery, yr (SD)	53.9 (13.2)	54.8 (10.4)	52.3 (13.3)	56.6 (13.1)	.069
Female, no. (%)	134 (91.8)	7 (87.5)	80 (90.9)	47 (94.0)	.584
BMI, kg/m <sup>2</sup> (SD)	26.4 (4.8)	25.8 (1.5)	26.0 (4.4)	27.3 (5.6)	.497
Prior spine surgery, no. (%) <sup>b</sup>	39 (26.9)	2 (25.0)	21 (23.9)	16 (32.7)	.512
ASA, no. (SD)	2.2 (0.6)	2.5 (0.5)	2.1 (0.6)	2.3 (0.7)	.106
Charlson Comorbidity Index, no. (SD)	1.2 (1.5)	2.1 (2.4)	0.8 (1.0)	1.9 (1.7)	<b>&lt;.001</b>
≥1 Comorbidity, no. (%)	94 (64.4)	6 (75.0)	49 (55.7)	39 (78.0)	.182, 1.000, <b>&lt;.001</b>
No. of comorbidities, no. (SD)	1.5 (1.6)	2.3 (2.9)	1.1 (1.2)	2.2 (1.8)	<b>.021</b>
Arthritis, no. (%)	44 (30.1)	2 (25.0)	20 (22.7)	22 (44.0)	.460, 1.000, <b>.009</b>
Hypertension, no. (%)	40 (27.4)	2 (25.0)	18 (20.5)	20 (40.0)	<b>.001</b>
Depression, no. (%)	28 (19.2)	2 (25.0)	16 (18.2)	10 (20.0)	.649, 1.000, <b>.001</b>
Gastric ulcer, no. (%)	24 (16.4)	2 (25.0)	10 (11.4)	12 (24.0)	<b>.031</b>
Osteoporosis, no. (%)	23 (15.8)	1 (12.5)	9 (10.2)	13 (26.0)	1.000, 449, <b>.009</b>
Smoker, no. (%) <sup>b</sup>	9 (6.5)	–	–	–	<b>.042</b>
Adult Spinal Deformity Frailty Index, no. (SD)	2.7 (1.6)	3.1 (2.5)	2.5 (1.4)	3.2 (1.6)	.670, .697, <b>.013</b>
					1.000, 1.000, <b>.035</b>

BMI = body mass index.

<sup>a</sup>Scoliosis subtypes include thoracic (apex T2 to T8-9, Cobb ≥75°), thoracolumbar (apex T8-9 to L1-2, Cobb ≥50°), lumbar (apex L1-2 to L4, Cobb ≥50°).

<sup>b</sup>Incomplete data for prior spine surgery (n = 1), smoking (n = 8).

<sup>c</sup>Kruskal-Wallis test and post hoc Dunn-Bonferroni pairwise comparisons, 1-way analysis of variance and post hoc pairwise comparisons, Fisher's exact test or Chi-squared test with post hoc pairwise comparisons.

<sup>d</sup>Bonferroni-adjusted thoracic vs thoracolumbar.

<sup>e</sup>Bonferroni-adjusted thoracic vs lumbar.

<sup>f</sup>Bonferroni-adjusted thoracolumbar vs lumbar.

Boldface type indicates statistical significance.

received operative treatment with potential for minimum 2-yr follow-up (Figure 2). Of these, 146 (82.0%) achieved minimum 2-yr follow-up and were the primary focus of this study. Baseline demographics and comorbidities are summarized for these 146 patients in Table 1. The distribution of SRS-Schwab thoracolumbar deformity classification sagittal modifiers<sup>19</sup> is depicted for the study cohort in Figure 3.

### Index Operations

Index operative data are summarized in Table 2. Some details included posterior-only approach (n = 84, 57.5%), mean posterior fusion length = 13.2 ± 3.7 levels, iliac fixation (n = 104, 72.2%, and 3-column osteotomy (3CO; n = 21, 14.4%). Additional posterior fusion data are presented in Supplemental Table 1.

### Radiographic and HRQL Outcomes

Radiographic parameters at baseline and last follow-up (mean radiographic follow-up = 3.2 ± 1.1 yr) are presented in Table 3. At baseline, lumbar scoliosis patients had worse GCM (4.8 vs

3.3 cm, P = .043) but less severe major curve magnitude (61.3° vs 67.4°, P = .032) compared to thoracolumbar scoliosis, respectively. Baseline sagittal spinopelvic measurements were significantly worse in lumbar vs thoracolumbar scoliosis. Most assessed coronal and sagittal radiographic parameters were significantly improved after surgery (Table 3). At last follow-up, the percent improvement of maximum coronal Cobb measurements was 32%, 48%, and 53% for thoracic, thoracolumbar, and lumbar scoliosis subgroups, respectively.

Table 4 summarizes mean HRQL outcome scores at baseline and last postoperative follow-up (mean clinical follow-up = 3.1 ± 1.1 yr). Sensitivity analysis for best and worst outcomes was performed (Supplemental Results). At baseline, lumbar scoliosis patients reported worse mean ODI (44.4 ± 20.5 vs 36.1 ± 18.0, P = .045), PCS (30.2 ± 10.8 vs 37.5 ± 10.7, P = .001), and SRS-22r pain (2.4 ± 0.9 vs 2.8 ± 0.9, P = .030) compared to thoracolumbar scoliosis, respectively. Improvements ≥1 MCID/SCB for assessed HRQL were achieved in 36% to 75% and 29% to 51% of patients, respectively (Figure 4). The percentages of patients without change of ≥1

**TABLE 2. Index Operative Data for 146 Adults With Severe Scoliosis and Minimum 2-Year Follow-up**

Parameter	All patients (n = 146)	Comparison of scoliosis subgroups			eP-value
		Thoracic (n = 8)	Thoracolumbar (n = 88)	Lumbar (n = 50)	
<b>Approach (%)</b>					
Posterior-only	84 (57.5)	5 (62.5)	49 (55.7)	30 (60.0)	.953
Anterior-posterior <sup>a</sup>	61 (41.8)	3 (37.5)	38 (43.2)	20 (40.0)	
Posterior levels fused (SD)	13.2 (3.7)	14.7 (3.5)	13.2 (3.7)	13.1 (3.8)	.477
<b>UIV location<sup>b</sup></b>					
T1-T6 (%)	99 (68.8)	6 (85.7)	62 (71.3)	31 (62.0)	.679
T7-T12 (%)	39 (27.1)	1 (14.3)	21 (24.1)	17 (34.0)	
Below T12 (%)	6 (4.2)	0 (0)	4 (4.6)	2 (4.0)	
<b>LIV location<sup>b</sup></b>					
Lumbar (%)	33 (22.9)	2 (28.6)	23 (26.4)	8 (16.0)	.583
Sacrum (%)	7 (4.9)	0 (0)	5 (5.7)	2 (4.0)	
Ilium (%)	104 (72.2)	5 (71.4)	59 (67.8)	40 (80.0)	
Any osteotomy (%)	107 (73.3)	7 (87.5)	66 (75.0)	34 (68.0)	.459
<b>SPO (%)</b>					
No. per patient (SD)	95 (65.1)	5 (62.5)	59 (67.0)	31 (62.0)	.804
	6.5 (2.8)	–	–	–	–
<b>3CO (%)</b>					
No. per patient (SD)	21 (14.4)	4 (50.0)	11 (12.5)	6 (12.0)	<b>f.033</b>
	1.0 (0)	–	–	–	–
<b>Interbody fusion (%)<sup>c</sup></b>					
	98 (67.1)	5 (62.5)	57 (64.8)	36 (72.0)	.693
<b>TLIF (%)</b>					
No. per patient (SD)	34 (23.3)	2 (25.0)	18 (20.5)	14 (28.0)	.573
	1.2 (0.5)	–	–	–	–
<b>ALIF (%)</b>					
No. per patient (SD)	54 (37.0)	3 (37.5)	35 (39.8)	16 (32.0)	.656
	3.2 (1.6)	–	–	–	–
<b>Operative duration, hours (SD)<sup>d</sup></b>					
	8.1 (3.4)	8.6 (3.5)	8.0 (3.2)	8.2 (3.9)	.587
<b>EBL, L (SD)<sup>d</sup></b>					
	1.8 (1.2)	2.2 (1.4)	1.7 (1.2)	1.8 (1.2)	.544
<b>LOS, d (SD)</b>					
	8.5 (4.6)	8.1 (2.4)	7.9 (3.7)	9.6 (5.9)	.267

3CO = three-column osteotomy; ALIF = anterior lumbar interbody fusion; EBL = estimated blood loss; LIV = lowermost instrumented vertebral level; LOS = length of index hospital stay; SPO = Smith-Petersen osteotomy; TLIF = transforaminal lumbar interbody fusion; UIV = uppermost instrumented vertebral level.

<sup>a</sup>Not shown is anterior-only approach in a single patient.

<sup>b</sup>Incomplete UIV and LIV data for 2 patients.

<sup>c</sup>Includes TLIF, ALIF, PLIF, XLIF, and trans-sacral.

<sup>d</sup>Includes both anterior and posterior procedures, if applicable.

<sup>e</sup>Kruskal-Wallis test, Fisher's exact test, Chi-squared test.

<sup>f</sup>Bonferroni-adjusted pairwise comparisons significant for thoracic vs thoracolumbar ( $P = .019$ ) and thoracic vs lumbar ( $P = .024$ ).

Boldface type indicates statistical significance.

MCID/SCB for assessed HRQL are presented in **Supplemental Figure 1**. Also, the percentages of patients with decline of  $\geq 1$  MCID/SCB for assessed HRQL are presented in **Supplemental Figure 2**. Bar charts of average baseline and postoperative HRQL scores (with standard deviation and range) are depicted for ODI, SF-36 PCS, SRS-22r total, and NRS back/leg pain in Figure 5.

### Summary of Complications

Table 5 summarizes types and rates of complications for all patients who achieved minimum 2-yr follow-up. A total of 191 complications were reported (92 minor/99 major), with timing as follows: 53 intraoperative, 55 early ( $<30$  d), and 83 delayed ( $>30$  d). Ninety-four (64.4%) patients had  $\geq 1$  complication, and 62 (42.5%) patients had  $\geq 1$  major complication (including

those that resulted in reoperations). The most common complications included rod fracture (13.0%), durotomy (12.3%), pleural effusion (11.6%), radiculopathy (8.2%), deep wound infection (8.2%), and proximal junctional kyphosis (7.5%). Thirty-seven (25.3%) patients had 1 to 5 reoperations for a total of 57 reoperations. The most common indications for reoperation were deep wound infection (11), rod fracture (10), and pseudarthrosis (5). Data for rod fractures are summarized in **Supplemental Table 2**. Data for iliac fixation and delayed complications are summarized in the **Supplemental Results**.

Table 6 summarizes complications for the 32 patients who did not achieve minimum 2-yr follow-up (mean follow-up = 0.74 yr). The general distribution and types of complications encountered in these patients were comparable to complication data for patients achieving 2-yr follow-up. See **Supplemental Results** for more details.

**TABLE 3. Comparison of Radiographic Parameters at Baseline and Last Postoperative Follow-up After Operative Treatment for Severe Scoliosis in 146 Symptomatic Adults<sup>a</sup>**

Coronal parameters (SD)	All patients (n = 146)	Thoracic (TH, n = 8)	Thoracolumbar (TL, n = 88)	Lumbar (L, n = 50)	TL vs L P-value <sup>b</sup>
<b>GCM, magnitude in cm</b>					
Baseline	3.8 (3.2)	3.2 (1.7)	3.3 (2.7)	4.8 (4.0)	<b>.043</b>
Final follow-up	2.8 (2.5)	2.8 (2.4)	2.4 (2.2)	3.5 (2.7)	<b>.012</b>
P-value (baseline vs final)	<b>.001</b>	.664	<b>.016</b>	<b>.029</b>	
<b>Pelvic obliquity,<sup>o</sup></b>					
Baseline	2.9 (2.3)	3.0 (3.2)	2.5 (2.1)	3.6 (2.5)	<b>.003</b>
Final follow-up	2.5 (2.0)	3.5 (2.0)	2.3 (1.9)	2.9 (2.3)	.371
P-value (baseline vs final)	0.383	0.225	0.902	0.321	
<b>Maximum coronal Cobb,<sup>o</sup></b>					
Baseline	66.2 (14.0)	83.7 (6.7)	67.4 (15.3)	61.3 (8.8)	<b>.032</b>
Final follow-up	34.1 (18.0)	57.0 (24.9)	35.1 (18.4)	28.6 (12.5)	.063
P-value (baseline vs final)	<b>&lt;.001</b>	<b>.020</b>	<b>&lt;.001</b>	<b>&lt;.001</b>	
<b>Sagittal parameters (SD)</b>					
<b>C7-S1 SVA, cm</b>					
Baseline	4.9 (6.7)	2.5 (6.1)	4.0 (6.2)	6.7 (7.2)	<b>.048</b>
Final follow-up	1.9 (5.6)	0.4 (5.8)	1.7 (5.0)	2.5 (6.6)	.626
P-value (baseline vs final)	<b>&lt;.001</b>	<b>.023</b>	<b>&lt;.001</b>	<b>&lt;.001</b>	
<b>Pelvic tilt,<sup>o</sup></b>					
Baseline	23.5 (10.0)	23.3 (10.2)	22.3 (10.1)	25.5 (9.4)	.069
Final follow-up	20.9 (9.9)	23.2 (9.0)	20.3 (9.4)	21.6 (11.0)	.757
P-value (baseline vs final)	<b>&lt;.001</b>	0.937	<b>.039</b>	<b>.003</b>	
<b>PI-LL mismatch,<sup>o</sup></b>					
Baseline	12.9 (20.9)	4.3 (21.7)	10.7 (20.8)	18.2 (20.1)	<b>.041</b>
Final follow-up	2.9 (16.5)	2.1 (13.6)	2.7 (15.4)	3.3 (19.0)	.773
P-value (baseline vs final)	<b>&lt;.001</b>	0.584	<b>&lt;.001</b>	<b>&lt;.001</b>	
<b>Lumbar lordosis T12-S1,<sup>o</sup></b>					
Baseline	36.8 (22.6)	53.3 (17.2)	38.9 (22.7)	30.5 (21.4)	<b>.035</b>
Final follow-up	51.2 (14.9)	57.7 (12.6)	51.1 (15.0)	50.5 (14.9)	.841
P-value (baseline vs final)	<b>&lt;.001</b>	0.350	<b>&lt;.001</b>	<b>&lt;.001</b>	
<b>Thoracic kyphosis T4-T12,<sup>o</sup></b>					
Baseline	-31.6 (18.9)	-44.5 (25.9)	-31.3 (18.4)	-30.0 (18.1)	.759
Final follow-up	-40.2 (15.2)	-37.5 (11.1)	-38.8 (15.3)	-43.0 (15.4)	.130
P-value (baseline vs final)	<b>&lt;.001</b>	0.337	<b>&lt;.001</b>	<b>&lt;.001</b>	

GCM = global coronal malalignment; LL = lumbar lordosis; PI = pelvic incidence; SVA = sagittal vertical axis.

<sup>a</sup>Wilcoxon signed-rank test and paired t-test were used for repeated measurements (baseline vs final f/u).

<sup>b</sup>Only thoracolumbar and lumbar are compared with Mann-Whitney U test and independent t-test.

Boldface type indicates statistical significance.

## DISCUSSION

Prior studies provided high-quality evidence to suggest potential benefits of operative treatment for ASD, despite high rates of associated complications.<sup>1,2,14,15,33</sup> However, ASD is heterogeneous and comprised varying subtypes and severity that may differentially impact treatment outcomes.<sup>34,35</sup> As such, an investigation focused on the subset of ASD with more severe scoliosis may be of interest to deformity surgeons, especially given the recently published multicenter trial, ASLS-1 (Adult Symptomatic Lumbar Scoliosis-1), which could be interpreted as evidence to support operative treatment for select ASLS patients.<sup>2</sup>

Results from the ASLS-1 trial and other multicenter operative vs nonoperative comparative studies demonstrated average baseline scoliosis of 28° to 57°, and some authors reported minimum scoliosis of only 10° for study inclusion.<sup>1,2,14,15,33</sup> Also, other ASD outcome studies with only operatively treated cohorts reported average baseline scoliosis of 37° to 54°.<sup>9,16,36</sup> Therefore, assessing surgical outcomes for symptomatic adults with larger, more severe coronal curves could potentially advance the field and facilitate future research. Of note, some of our coauthors recently published surgical outcomes data for adults with severe TL/L scoliosis ≥75°, but this was a small single-institution case series comprised only 22 patients.<sup>17</sup> In the present study, we rigorously investigated a much larger surgical cohort

**TABLE 4. Comparison of Clinical Outcomes at Baseline and Last Postoperative Follow-up After Operative Treatment for Severe Scoliosis in 146 Symptomatic Adults**

Parameter (SD)	All patients (n = 146)	Thoracic (TH, n = 8)	Thoracolumbar (TL, n = 88)	Lumbar (L, n = 50)	TH vs TL vs L P-value <sup>b</sup>
<b>ODI</b>					
Baseline	39.0 (19.5)	36.6 (25.6)	36.1 (18.0)	44.4 (20.5)	<b>.045 (TL vs L)</b>
Final follow-up	25.7 (19.6)	31.0 (21.3)	25.0 (20.3)	26.1 (18.3)	.583
P-value <sup>a</sup>	<b>&lt;.001*</b>	0.500	<b>&lt;.001</b>	<b>&lt;.001*</b>	
<b>SF-36 PCS</b>					
Baseline	34.9 (11.4)	34.6 (14.8)	37.5 (10.7)	30.2 (10.8)	<b>.001 (TL vs L)*</b>
Final follow-up	41.0 (10.9)	39.5 (10.8)	41.8 (11.5)	39.9 (9.8)	.444
P-value <sup>a</sup>	<b>&lt;.001*</b>	0.612	<b>&lt;.001</b>	<b>&lt;.001*</b>	
<b>SF-36 MCS</b>					
Baseline	47.9 (13.1)	41.8 (16.1)	47.0 (13.3)	50.5 (12.0)	.163
Final follow-up	51.1 (12.3)	50.8 (13.7)	50.5 (12.4)	52.3 (12.1)	.550
P-value <sup>a</sup>	<b>.010</b>	0.307	<b>.008</b>	0.566	
<b>SRS-22r total</b>					
Baseline	2.9 (0.7)	2.8 (0.9)	3.0 (0.7)	2.9 (0.7)	.740
Final follow-up	3.8 (0.7)	3.7 (0.6)	3.7 (0.8)	3.8 (0.7)	.864
P-value <sup>a</sup>	<b>&lt;.001</b>	<b>.035</b>	<b>&lt;.001</b>	<b>&lt;.001</b>	
<b>SRS-22r activity</b>					
Baseline	3.1 (1.0)	3.2 (1.4)	3.1 (0.9)	3.0 (1.0)	.734
Final follow-up	3.7 (0.9)	3.7 (0.9)	3.6 (0.9)	3.6 (0.9)	.836
P-value <sup>a</sup>	<b>&lt;.001*</b>	0.260	<b>&lt;.001*</b>	<b>&lt;.001*</b>	
<b>SRS-22r pain</b>					
Baseline	2.6 (0.9)	2.8 (1.2)	2.8 (0.9)	2.4 (0.9)	<b>.030 (TL vs L)</b>
Final follow-up	3.5 (1.0)	3.7 (0.6)	3.5 (1.0)	3.5 (1.0)	.983
P-value <sup>a</sup>	<b>&lt;.001*</b>	0.086	<b>&lt;.001*</b>	<b>&lt;.001*</b>	
<b>SRS-22r appearance</b>					
Baseline	2.4 (0.8)	2.3 (0.8)	2.5 (0.7)	2.4 (0.8)	.935
Final follow-up	3.8 (0.9)	3.5 (0.9)	3.7 (0.9)	3.8 (0.9)	.440
P-value <sup>a</sup>	<b>&lt;.001*</b>	<b>.013*</b>	<b>&lt;.001*</b>	<b>&lt;.001*</b>	
<b>SRS-22r mental</b>					
Baseline	3.6 (0.9)	3.3 (0.8)	3.5 (1.0)	3.8 (0.9)	.196
Final follow-up	3.9 (0.9)	3.8 (0.7)	3.8 (0.9)	4.1 (0.9)	.126
P-value <sup>a</sup>	<b>&lt;.001</b>	0.195	<b>&lt;.001</b>	<b>.005</b>	
<b>SRS-22r satisfaction</b>					
Baseline	2.8 (1.1)	2.2 (0.8)	2.8 (0.9)	2.7 (1.3)	.174
Final follow-up	4.3 (0.9)	4.2 (0.7)	4.2 (0.9)	4.4 (0.8)	.499
P-value <sup>a</sup>	<b>&lt;.001</b>	<b>.001</b>	<b>&lt;.001</b>	<b>&lt;.001</b>	
<b>NRS back pain</b>					
Baseline	6.6 (2.4)	6.9 (2.3)	6.4 (2.3)	6.8 (2.5)	.454
Final follow-up	3.8 (3.0)	5.0 (2.5)	3.5 (3.0)	4.1 (3.0)	.240
P-value <sup>a</sup>	<b>&lt;.001*</b>	0.186	<b>&lt;.001*</b>	<b>&lt;.001*</b>	
<b>NRS leg pain</b>					
Baseline	3.7 (3.2)	3.6 (3.4)	3.4 (3.2)	4.2 (3.3)	.404
Final follow-up	2.5 (2.8)	3.6 (3.2)	2.3 (2.8)	2.7 (2.8)	.234
P-value <sup>a</sup>	<b>.001</b>	0.893	<b>.022</b>	<b>.006</b>	

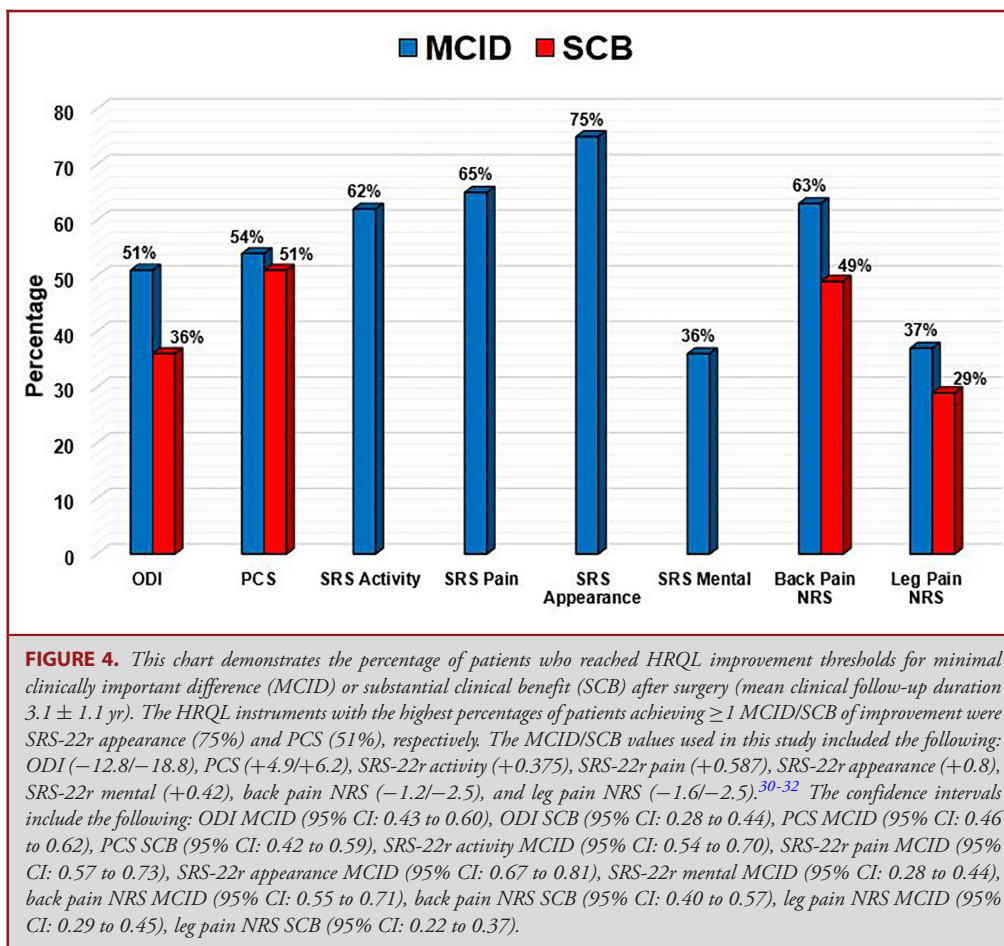
MCS = Mental Component Summary; NRS = Numerical Rating Scale; ODI = Oswestry Disability Index; PCS = Physical Component Summary; SF-36 = Short Form-36; SRS = Scoliosis Research Society-22r questionnaire.

<sup>a</sup>Comparison of baseline vs final f/u scores using Wilcoxon signed-rank test and paired t-test

<sup>b</sup>Comparison of scoliosis subgroups performed using Mann-Whitney U test, independent t-test, Kruskal-Wallis test, and 1-way analysis of variance; only significant Bonferroni-corrected pairwise comparisons are listed.

Boldface type indicates statistical significance.

\*Denotes significant P-values with mean score change ≥1 minimal clinically important difference (MCID); there is no MCID reported for SF-36 MCS, SRS-22r total, and SRS-22r satisfaction.



(n = 146) of consecutive patients extracted from a multi-institutional database, which likely improves its generalizability.

Our study inclusion criteria defined 75° and 50° as minimum curve magnitudes for severe thoracic and thoracolumbar/lumbar scoliosis, respectively. Application of study criteria generated subgroups of thoracic (n = 8; 5.5%), thoracolumbar (n = 88; 60.3%), and lumbar scoliosis (n = 50; 34.2%). Of note, the smaller thoracic subgroup may reflect greater tolerance of coronal curves in the thoracic spine compared to thoracolumbar/lumbar spine,<sup>34,37</sup> and this may partly explain why fewer pursued operative treatment. The average coronal Cobb angles for thoracic, thoracolumbar, and lumbar scoliosis subgroups measured 84°, 67°, and 61°, respectively. These coronal curves were larger than the reported averages in the aforementioned studies described above,<sup>1,2,9,14-16,33,36</sup> and likely would be considered severe by most adult deformity surgeons.

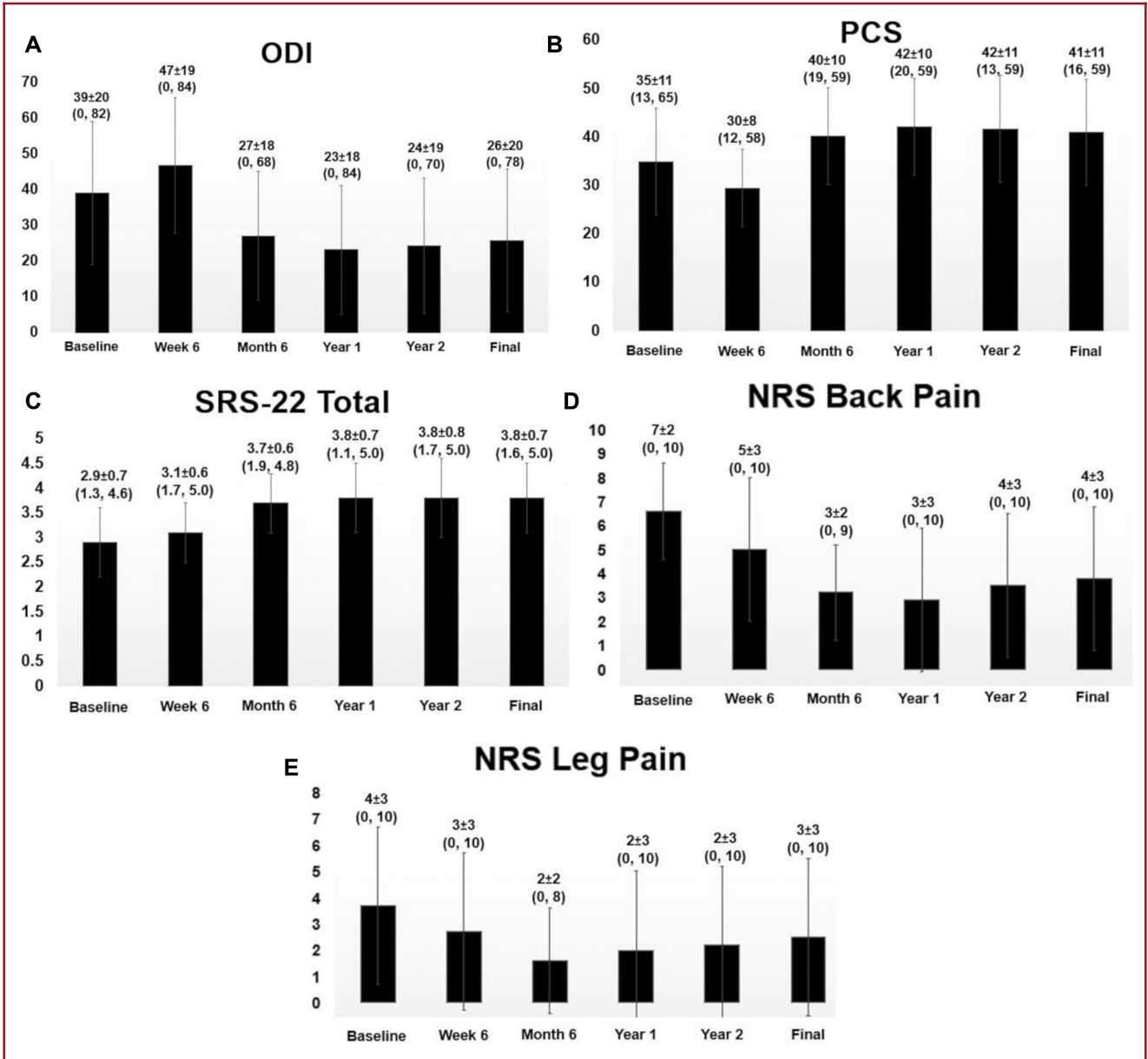
### Radiographic Outcomes

After operative treatment, radiographic analysis at final follow-up demonstrated scoliosis correction (percent improvement of

maximum coronal Cobb) of 32%, 48%, and 53% for thoracic, thoracolumbar, and lumbar subgroups, respectively. These results were similar to correction rates reported by other adult scoliosis studies.<sup>1,2</sup> Next, an assessment of sagittal spinopelvic measures demonstrated significant improvement at last follow-up, and final sagittal alignment was comparable between subgroups despite lumbar scoliosis patients starting with significantly worse baseline sagittal deformity (SVA, LL, PI-LL mismatch).

### Baseline HRQL

Baseline assessment of the current study cohort demonstrated substantial pain and disability. Notably, the patients in the lumbar scoliosis subgroup, despite having lowest average coronal curve magnitude among scoliosis subgroups, reported the worst mean HRQL scores. This is consistent with previous reports that lower apical level of scoliosis (eg, TL/L vs TH scoliosis) may be associated with significantly worse pain and disability.<sup>18,37</sup> However, it is possible that the poor baseline HRQL for the lumbar scoliosis subgroup may be partly explained by their concomitant sagittal deformity, which was more severe than the other subgroups.<sup>38,39</sup>



**FIGURE 5.** These bar charts A-E depict average baseline and postoperative HRQL scores (including standard deviation and range) for the entire study cohort. The HRQL instruments included ODI, SF-36 PCS, SRS-22r total, and NRS back/leg pain. Postoperative assessment of HRQL was performed at specific time intervals: 6 wk, 6 mo, 1 yr, 2 yr, and each year thereafter up to 5 yr. For illustrative purposes, the final time point represents the mean clinical follow-up duration for this study (3.1 ± 1.1 yr). The postoperative recovery process was notable for worse ODI and SF-36 PCS at 6 wk, followed by improvement at 6 mo to final follow-up.

The present study’s lumbar scoliosis subgroup had mean baseline PCS score of 30.2, which was similar to results by Bess et al,<sup>34</sup> which reported PCS score of 29.3 for symptomatic ASD patients with combined lumbar scoliosis ≥20° and sagittal deformity. For the other assessed HRQL instruments in the current study, the overall mean baseline scores for ODI and SRS-22r domains were worse in comparison to the randomized operative cohort of the ASLS-1 trial, which defined adult

symptomatic lumbar scoliosis as minimum 30° lumbar coronal curve and ODI ≥20 or SRS-22r subdomain scores ≤4.0 for activity/function, pain, or appearance/self-image.<sup>2</sup> Collectively, our study findings may provide evidence to suggest that symptomatic adult patients with severe scoliosis have substantial pain and disability, possibly worse than many other ASD subtypes, and this likely drives patients to choose operative management.<sup>40</sup>

**TABLE 5. Summary of Complications for 146 Adults With Severe Scoliosis Treated Surgically With Minimum 2-Year Follow-up<sup>a</sup>**

Complication category	No. of minor/major complications (%)			
	Intraop	Early (<30 d)	Delayed (>30 d)	Total
<b>Operative</b>	22/10 (21.9)	0/4 (2.7)	0/1 (0.7)	22/15 (25.3)
	3 reop	0 reop	1 reop	4 reop
Anemia <sup>b</sup>	0/0	0/2 (1.4)	0/0	0/2 (1.4)
Dural tear	18/0 (12.3)	0/0	0/0	18/0 (12.3)
Excessive blood loss <sup>b</sup>	0/5 (3.4)	0/0	0/0	0/5 (3.4)
Lymphocele	0/1 (0.7)	0/1 (0.7)	0/0	0/2 (1.4)
Monitoring anomaly	2/3 (3.4)	0/0	0/0	2/3 (3.4)
	3 reop			3 reop
Pleural injury	2/0 (1.4)	0/0	0/0	2/0 (1.4)
Positioning	0/0	0/1 (0.7)	0/0	0/1 (0.7)
Retained sponge	0/0	0/0	0/1 (0.7)	0/1 (0.7)
			1 reop	1 reop
Vascular injury	0/1 (0.7)	0/0	0/0	0/1 (0.7)
<b>Implant</b>	0/3 (2.1)	1/0 (0.7)	9/22 (21.2)	10/25 (24.0)
	2 reop	0 reop	14 reop	16 reop
Interbody spacer dislodgement	0/2 (1.4)	0/0	0/0	0/2 (1.4)
	1 reop			1 reop
Implant loosening or dislodgement	0/0	0/0	2/2 (2.7)	2/2 (2.7)
			2 reop	2 reop
Painful implant	0/0	0/0	3/1 (2.7)	3/1 (2.7)
			1 reop	1 reop
Implant prominence	0/0	0/0	3/1 (2.7)	3/1 (2.7)
			1 reop	1 reop
Rod breakage	0/0	0/0	1/18 (13.0)	1/18 (13.0)
			10 reop	10 reop
Screw medial breach	0/0	1/0 (0.7)	0/0	1/0 (0.7)
Screw nerve impingement	0/1 (0.7)	0/0	0/0	0/1 (0.7)
	1 reop			1 reop
<b>Cardiopulmonary</b>	4/2 (4.1)	14/7 (14.4)	1/2 (2.1)	19/11 (20.5)
	1 reop	1 reop	0 reop	2 reop
Arrythmia	0/0	1/0 (0.7)	0/0	1/0 (0.7)
Tachyarrhythmia	1/1 (1.4)	1/0 (0.7)	0/0	2/1 (2.1)
	1 reop			1 reop
Deep vein thrombosis	0/0	0/3 (2.1)	0/0	0/3 (2.1)
Pulmonary embolism	0/1 (0.7)	0/3 (2.1)	0/1 (0.7)	0/5 (3.4)
Pleural effusion	2/0 (1.4)	12/1 (8.9)	1/1 (1.4)	15/2 (11.6)
		1 reop		1 reop
Other	1/0 (0.7)	1/0 (0.7)	1/0 (0.7)	1/0 (0.7)
<b>Radiographic</b>	0/0	0/1 (0.7)	10/18 (19.2)	10/19 (19.9)
	0 reop	1 reop	15 reop	16 reop
Adjacent segment disease	0/0	0/0	2/2 (2.7)	2/2 (2.7)
			2 reop	2 reop
Coronal imbalance	0/0	0/1 (0.7)	0/2 (1.4)	0/3 (2.1)
		1 reop	2 reop	3 reop
Distal junctional kyphosis	0/0	0/0	0/1 (0.7)	0/1 (0.7)
Proximal junctional kyphosis	0/0	0/0	7/4 (7.5)	7/4 (7.5)
			3 reop	3 reop
Pseudarthrosis	0/0	0/0	0/6 (4.1)	0/6 (4.1)
			5 reop	5 reop
Sagittal imbalance	0/0	0/0	1/3 (2.7)	1/3 (2.7)
			3 reop	3 reop

TABLE 5. Continued

Complication category	No. of minor/major complications (%)			
	Intraop	Early (<30 d)	Delayed (> 30 d)	Total
<b>Neurological</b>	6/4 (6.8)	2/2 (2.7)	9/3 (8.2)	17/9 (17.8)
	3 reop	0 reop	2 reop	5 reop
Bowel/bladder deficit	0/0	0/0	1/0 (0.7)	1 (0.7)
Mental status change	3/0 (2.1) <sup>c</sup>	0/0	0/0	3/0 (2.1)
Motor deficit	1/4 (3.4)	0/0	1/1 (1.4)	2/5 (4.8)
	3 reop		1 reop	4 reop
Radiculopathy	2/0 (1.4)	2/0 (1.4)	7/1 (5.5)	11/1 (8.2)
			1 reop	1 reop
Seizure	0/0	0/0	0/1 (0.7)	0/1 (0.7)
Stroke	0/0	0/2 (1.4)	0/0	0/2 (1.4)
<b>Infection</b>	1/0 (0.7)	3/9 (8.2)	1/6 (4.8)	5/15 (13.7)
	0 reop	5 reop	6 reop	11 reop
Deep wound infection	0/0	0/6 (4.1)	0/6 (4.1)	0/12 (8.2)
		5 reop	6 reop	11 reop
Pneumonia	0/0	0/2 (1.4)	0/0	0/2 (1.4)
Sepsis	0/0	0/1 (0.7)	0/0	0/1 (0.7)
Superficial	0/0	1/0 (0.7)	0/0	1/0 (0.7)
Urinary tract infection	1/0 (0.7)	2/0 (1.4)	1/0 (0.7)	4/0 (2.7)
<b>Gastrointestinal</b>	1/0 (0.7)	6/2 (5.5)	0/0	7/2 (6.2)
	0 reop	1 reop	0 reop	1 reop
Cholecystitis	0/0	0/1 (0.7)	0/0	0/1 (0.7)
		1 reop		1 reop
Ileus	1/0 (0.7)	6/1 (4.8)	0/0	7/1 (5.5)
<b>Wound (excluding infection)</b>	0/0	2/2 (2.7)	0/1 (0.7)	2/3 (3.4)
	0 reop	1 reop	1 reop	2 reop
Dehiscence	0/0	1/1 (1.4)	0/1 (0.7)	1/2 (2.1)
		1 reop	1 reop	2 reop
Erythema/drainage	0/0	0/1 (0.7)	0/0	0/1 (0.7)
Hematoma/seroma	0/0	1/0 (0.7)	0/0	1/0 (0.7)
Mortality	0/0 (0)	0/0 (0)	0/0 (0)	0/0 (0)
Total (minor/major) reoperations	53 (34/19)	55 (28/27)	83 (30/53)	191 (92/99)
	9 reop	9 reop	39 reop	57 reop
No. of patients affected (%)	37 (25.3)	41 (28.1)	52 (35.6)	94 (64.4)

<sup>a</sup>The number of reoperations indicates the subset of major complications associated with need for reoperation. Complications were classified as major if it substantially prolonged inpatient hospital stay, involved further invasive procedures, caused prolonged or significant morbidity, or if it resulted in mortality.

<sup>b</sup>Estimated blood loss (EBL) >4 L was classified as major complication; acute blood-loss anemia with EBL <4 L was classified as minor complication.

<sup>c</sup>For mental status changes, this could include the same day of index surgery.

## Postoperative HRQL

Our results demonstrated significant improvement in the mean scores for assessed HRQL measures. Further analysis revealed that the entire cohort's postoperative recovery was characterized by an initial increase in disability and decrease in physical health status at 6 wk, and then improvement at 6 mo to last follow-up. At final follow-up, patients had the highest rate of improving by  $\geq 1$  MCID for SRS-22r appearance (75%) and the lowest rate of improving  $\geq 1$  MCID for SRS-22r mental (36%). Of note, the percentages for patients achieving MCID improvement in this study were consistent with previous ASD surgical reports.<sup>1</sup> For example, a study by Liu et al<sup>31</sup> demonstrated similar rates of MCID improvement for the SRS-22r

appearance and SRS-22r mental subdomains: 74% and 43%, respectively.

## Complications

This study had good follow-up (82%) at minimum 2-yr postoperatively, and likely represents the most comprehensive collection of complications associated with operative treatment of severe adult scoliosis. We found high rates of complications, which is consistent with previous multicenter findings reported by Smith and colleagues.<sup>3,5</sup> For the 32 potentially eligible patients who did not achieve minimum 2-yr follow-up, further subanalysis did not demonstrate disproportionate complication rates that could account for their lack of follow-up.

**TABLE 6. Summary of Complications for 32 Adults With Severe Scoliosis Treated Surgically Who Did Not Achieve Minimum 2-Year Follow-up<sup>a</sup>**

Complication category	No. of minor/major complications (%)			
	Intra-op	Early (<30 d)	Delayed (>30 d)	Total
Operative	3/3 (18.8) 1 reop	0/0 0 reop	0/0 0 reop	3/3 (18.8) 1 reop
Implant	0/0 0 reop	0/1 (3.1) 1 reop	0/1 (3.1) 0 reop	0/2 (6.3) 1 reop
Cardiopulmonary	1/0 (3.1) 0 reop	1/4 (15.6) 0 reop	0/2 (6.3) 0 reop	2/6 (25.0) 0 reop
Radiographic	0/0 0 reop	0/2 (6.3) 2 reop	4/1 (15.6) 1 reop	4/3 (21.9) 3 reop
Neurological	1/0 (3.1) 0 reop	1/1 (6.3) 1 reop	2/2 (12.5) 1 reop	4/3 (21.9) 2 reop
Infection	0/0 0 reop	1/2 (9.4) 1 reop	1/1 (6.3) 0 reop	2/3 (15.6) 1 reop
Gastrointestinal	0/0 0 reop	3/0 (9.4) 0 reop	1/0 (3.1) 0 reop	4/0 (12.5) 0 reop
Total (minor/major) reoperations	8 (5/3) 1 reop	16 (6/10) 5 reop	15 (8/7) 2 reop	39 (19/20) 8 reop
No. of patients affected (%)	8 (25.0)	12 (37.5)	9 (28.1)	19 (59.4)

<sup>a</sup>Overall mean follow-up duration was 0.74 yr. When clinical and radiographic follow-up duration was different, the shorter duration was used to avoid potentially overestimating the mean follow-up. The number of reoperations indicates the subset of major complications associated with need for reoperation.

**Strengths and Limitations**

The strengths of this study include its prospective data collection using onsite coordinators, use of centralized auditing, multi-institutional design, standardized methods of radiographic measurement, use of validated standard questionnaires for HRQL assessment, and large cohort. To our knowledge, the current study represents the first multicenter investigation of surgical outcomes in the largest ASD cohort of severe scoliosis. Therefore, these findings may represent the most complete assessment of surgical outcomes for an underinvestigated subset of ASD.

Limitations include the retrospective design of the current analysis, which could potentially lead to underestimation of certain complications. Next, given that the current study utilized multicenter data (International Spine Study Group [ISSG]), the readership should be aware of the potential patient overlap with prior ISSG publications<sup>1,3,5,31</sup> and interpret the current findings accordingly. Also, patient selection, choice of surgical approach and techniques, and postoperative management (including use of postoperative bracing) were decided by the treating deformity surgeons. It is also important to note that both the preoperative review process to select surgical candidates and the operative treatment plan are not commonly standardized across multicenter ASD outcome studies, including the present study. As such, surgeon treatment preference and institutional practices may have influenced outcomes. We acknowledge this limitation and the potential selection bias in this study. Despite these study limitations, the current study methodology assessed many medical comorbidities (including osteoporosis) and preoper-

ative risk scores (Charlson Comorbidity Index, ASA physical status classification, ASD Frailty Index), which are presented in Table 1. Therefore, other surgeons may still benefit from the data, which may potentially help guide future selection processes and workflow management for treatment of severe adult scoliosis. In addition, our results demonstrated a wide range of MCID improvement for the assessed HRQL, which was consistent with prior literature.<sup>1,31</sup> To provide a thorough assessment of the range of clinical outcomes, we presented data for the percentages of patients who did not change or declined by  $\geq 1$  MCID/SCB.

**CONCLUSION**

Study results demonstrated that surgery for symptomatic ASD patients with severe scoliosis (thoracic curve  $\geq 75^\circ$ , thoracolumbar curve  $\geq 50^\circ$ , lumbar curve  $\geq 50^\circ$ ) was associated with significant improvements in biplanar radiographic alignment, back/leg pain, and overall mean HRQL outcome scores at minimum 2-yr follow-up. Although associated complication rates were high, this was consistent with other outcome studies, including those with less severe scoliosis. This study may represent the most comprehensive assessment of surgical outcomes/complications for adults with severe scoliosis, which can provide novel benchmarks, improve patient counseling, and facilitate future research efforts.

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**Supplemental Figure 1.** Patients (%) with severe scoliosis without gain/loss of at least 1 MCID/SCB after ASD surgery. This chart demonstrates the percentage of patients who did not change by at least 1 minimal clinically important difference (MCID) or substantial clinical benefit (SCB) after surgery. The confidence intervals include the following: ODI MCID (95% CI: 0.32 to 0.49), ODI SCB (95% CI: 0.52 to 0.68), PCS MCID (95% CI: 0.20 to 0.35), PCS SCB (95% CI: 0.27 to 0.43), SRS-22r activity MCID (95% CI: 0.17 to 0.31), SRS-22r pain MCID (95% CI: 0.22 to 0.37), SRS-22r appearance MCID (95% CI: 0.19 to 0.33), SRS-22r mental MCID (95% CI: 0.47 to 0.64), back pain NRS MCID (95% CI: 0.20 to 0.35), back pain NRS SCB (95% CI: 0.38 to 0.54), leg pain NRS MCID (95% CI: 0.38 to 0.54), leg pain NRS SCB (95% CI: 0.50 to 0.66).

**Supplemental Figure 2.** Patients (%) with severe scoliosis who declined by at least 1 MCID/SCB after ASD surgery. This chart demonstrates the percentage of patients who declined by at least 1 minimal clinically important difference (MCID) or substantial clinical benefit (SCB) after surgery. The confidence intervals include the following: ODI MCID (95% CI: 0.04 to 0.14), ODI SCB (95% CI: 0.02 to 0.09), PCS MCID (95% CI: 0.13 to 0.27), PCS SCB (95% CI: 0.10 to 0.22), SRS-22r activity MCID (95% CI: 0.09 to 0.21), SRS-22r pain MCID (95% CI: 0.03 to 0.11), SRS-22r appearance MCID (95% CI: 0 to 0.02), SRS-22r mental MCID (95% CI: 0.05 to 0.15), back pain NRS MCID (95% CI: 0.05 to 0.16), back pain NRS SCB (95% CI: 0.02 to 0.11), leg pain NRS MCID (95% CI: 0.11 to 0.24), leg pain NRS SCB (95% CI: 0.08 to 0.20).

**Supplemental Table 1.** Summary of available posterior allograft and BMP2 data for index operations.

**Supplemental Table 2.** Summary of the 16 patients with rod fractures reported in this study.

**Supplemental Results.**

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