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Durability of Satisfactory Functional Outcomes Following Surgical Adult Spinal Deformity Correction: A 3-Year Survivorship Analysis

BACKGROUND: Despite reports showing positive long-term functional outcomes following adult spinal deformity (ASD)-corrective surgery, it is unclear which factors affect the durability of these outcomes.

OBJECTIVE: To assess durability of functional gains following ASD-corrective surgery; determine predictors for postoperative loss of functionality.

METHODS: Surgical ASD patients > 18 yr with 3-yr Oswestry Disability Index (ODI) follow-up, and 1-yr postoperative (1Y) ODI scores reaching substantial clinical benefit (SCB) threshold (SCB < 31.3 points). Patients were grouped: those sustaining ODI at SCB threshold beyond 1Y (sustained functionality) and those not (functional decline). Kaplan-Meier survival analysis determined postoperative durability of functionality. Multivariate Cox regression assessed the relationship between patient/surgical factors and functional decline, accounting for age, sex, and levels fused.

RESULTS: All 166 included patients showed baseline to 1Y functional improvement (mean ODI: 35.3 ± 16.5-13.6 ± 9.2, $P < .001$). Durability of satisfactory functional outcomes following the 1Y postoperative interval was 88.6% at 2-yr postoperative, and 71.1% at 3-yr postoperative (3Y). Those sustaining functionality after 1Y had lower baseline C2-S1 sagittal vertical axis (SVA) and T1 slope (both $P < .05$), and lower 1Y thoracic kyphosis ($P = .035$). From 1Y to 3Y, patients who sustained functionality showed smaller changes in alignment: pelvic incidence minus lumbar lordosis, SVA, T1 slope minus cervical lordosis, and C2-C7 SVA (all $P < .05$). Those sustaining functionality beyond 1Y were also younger, less frail at 1Y, and had lower rates of baseline osteoporosis, hypertension, and lung disease (all $P < .05$). Lung disease (Hazard Ratio:4.8 [1.4-16.4]), 1Y frailty (HR:1.4 [1.1-1.9]), and posterior approach (HR:2.6 [1.2-5.8]) were associated with more rapid decline.

CONCLUSION: Seventy-one percent of ASD patients maintained satisfactory functional outcomes by 3Y. Of those who failed to sustain functionality, the largest functional decline occurred 3-yr postoperatively. Frailty, preoperative comorbidities, and surgical approach affected durability of functional gains following surgery.

KEY WORDS: Adult spinal deformity, Disability, Functionality, Outcomes, Surgical correction

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Symptomatic adult spinal deformity (ASD) can have a profound impact on health-related quality of life (HRQoL), resulting in patient-reported disability levels comparable to those of cancer or diabetes.[1] While ASD is a complex disease with multiple etiologies, age-related degeneration of spinal elements is a common driver of progressive deformity. As the elderly population in the United States has grown over the past few decades, so too

ABBREVIATIONS: ASD, adult spinal deformity; **ASD-FI,** adult spinal deformity frailty index; **BMI,** body mass index; **CCI,** Charlson Comorbidity Index; **EBL,** estimated blood loss; **HRQoL,** health-related quality of life; **LOS,** length of stay; **ODI,** Oswestry Disability Index; **PI-LL,** pelvic incidence minus lumbar lordosis; **PT,** pelvic tilt; **SCB,** substantial clinical benefit; **SPF-36,** 36-item short form survey; **TS-CL,** T1 slope minus cervical lordosis; **TK,** thoracic kyphosis; **1Y,** 1-yr postoperative; **2Y,** 2-yr postoperative; **3Y,** 3-yr postoperative has the incidence of spinal surgery, with some studies reporting a 2-fold increase in the number of ASD-corrective surgeries from 2000 to 2010.[2] For elderly patients and patients with severe thoracolumbar deformity, operative ASD treatment has been shown to provide significant relief of pain and disability; however, hospital costs associated with surgery may eclipse $100,000 per patient, and can be driven even higher by complications, readmissions, and reoperations.[3-5] As such, durable clinical outcomes are key to optimizing both the physical and fiscal value of ASD-corrective surgery.

Currently, there are few studies investigating the long-term durability of ASD-corrective surgery. In a cohort of 113 operative ASD patients, Bridwell et al[6] showed significant postoperative improvements in patient-reported pain and radiographic alignment, which showed little change between 2-yr and 3- to 5-yr postoperative follow-up points. Another study tracking 84 operative ASD patients similarly showed postoperative improvements in clinical outcomes that remained stable from 1- to 3-yr follow-up.[7] Although important contributions to the literature, these studies do not report the proportion of patients that showed postoperative functional decline, instead only presenting population mean scores for patient-reported outcomes. Furthermore, while these studies show statistically significant pre- to postoperative changes in patient-reported outcomes, they do not translate statistical improvement in HRQoL instruments to meaningful clinical improvement.

Given the widespread use of patient-reported outcome instruments in tracking functional gains of surgical ASD patients, a number of studies have developed criteria for defining clinical success following spine surgery based on specific HRQoL score thresholds.[8,9] For example, in a population of 357 lumbar fusion patients, Glassman et al[10] compared Oswestry Disability Index (ODI) scores and global assessment rating anchor responses to develop a HRQoL score threshold indicative of substantial clinical benefit (SCB). While rates of reaching this SCB threshold following ASD-corrective surgery have been reported in the range of 16% to 48%, the literature lacks studies investigating the long-term durability of these clinically meaningful functional outcomes beyond 2-yr.[11]

Effective ASD-corrective surgery entails substantial reduction of patient-reported pain and disability; however, surgical intervention should not be considered successful unless clinical benefit is sustained over time. The goal of our study is to assess the durability of satisfactory functional outcomes for patients that showed initial functional gain following ASD-corrective surgery, and to determine predictors for postoperative loss of functionality.

METHODS

Data Source

This study is a retrospective review of a prospective, multicenter ASD database from 2009 to 2017. Patients were enrolled at 12 participating centers around the United States, and the Institutional Review Board Approval was obtained at each site prior to enrollment. Database inclusion criteria were patients $>$ 18 yr undergoing either operative or nonoperative treatment for ASD, defined as: coronal Cobb angle $\geq 20^\circ$, sagittal vertical axis (SVA, distance between C7 plumb line and sacral posterior superior margin) $\geq$ 5 cm, pelvic tilt $\geq 25^\circ$ and/or thoracic kyphosis (TK) $> 60^\circ$. Database exclusion criteria were patients with spinal deformity of neuromuscular etiology, presence of active infection, or malignancy. Included in the present study were surgical ASD patients meeting the 1-yr postoperative (1Y) SCB threshold for the ODI ($<$ 31.3, as previously published for lumbar fusion patients).[10] Additional study inclusion criteria were available preoperative, 1Y, and 3-yr postoperative (3Y) ODI data.

Each institution obtained approval from their local Institutional Review Board to enroll patients in the prospective database and informed consent was obtained from each patient.

Data Collection and Radiographic Assessment

Patient demographic data collected for this study were age, sex, body mass index (BMI), frailty as assessed by the adult spinal deformity frailty index (ASD-FI), and comorbidity status, including Charlson Comorbidity Index (CCI). Surgical data included surgical approach, operative time, estimated blood loss (EBL), and length of stay (LOS). Patient low-back disability was assessed at baseline and follow-up intervals using ODI score. Overall patient physical function was also assessed using the 36-item short form survey (SF-36) physical component score. Complication data, including major complications (as previously described by Schwab et al[12]), were gathered on standardized data collection forms.

Full length free-standing lateral spine radiographs (36" cassette) were used to assess patients at baseline and follow-up intervals. Radiographs were analyzed using SpineView® (ENSAM, Laboratory of Biomechanics) software according to validated and standardized techniques previously described in the literature.[13-15] Spinopelvic radiographic parameters assessed included are shown in Figure 1, and include pelvic tilt (PT: angle between the vertical and the line through the sacral midpoint to the center of the 2 femoral heads) and pelvic incidence minus lumbar lordosis (PI-LL: mismatch between pelvic incidence and lumbar lordosis). Global sagittal alignment was parameters assessed included SVA (C7-S1 SVA: C7 plumb line relative to the posterosuperior corner of S1) and C2-S1 SVA. Regional and cervical alignment were assessed using thoracic T4-T12 TK, T1 slope (T1S: angle subtended by superior T1 endplate and the horizontal), C2-C7 cervical lordosis (CL), T1 slope minus cervical lordosis (TS-CL), and C2-C7 SVA (cSVA).

Statistical Analysis

All statistical tests were performed with SPSS software (v21.0, IBM). Included patients were stratified into 2 cohorts by durability of satisfactory postoperative clinical outcomes: those who sustained ODI scores at the SCB threshold beyond 1-yr (sustained functionality), and those who did not (functional decline). Shapiro-Wilk tests assessed normality of data prior to means comparisons. Paired samples *t*-tests and Wilcoxon Signed Rank tests assessed overall differences in clinical and radiographic data between baseline and follow-up time points, as appropriate. Chi squared with Fisher's exact tests, independent samples *t*-tests, and Mann Whitney *U*-tests assessed differences in demographic, surgical, and clinical data between cohorts at baseline and available follow-up intervals, as appropriate. Kaplan-Meier analysis assessed the durability of satisfactory clinical outcomes at 2- and 3-yr postoperative intervals. Cox proportional hazards regression assessed the effect of patient and surgical

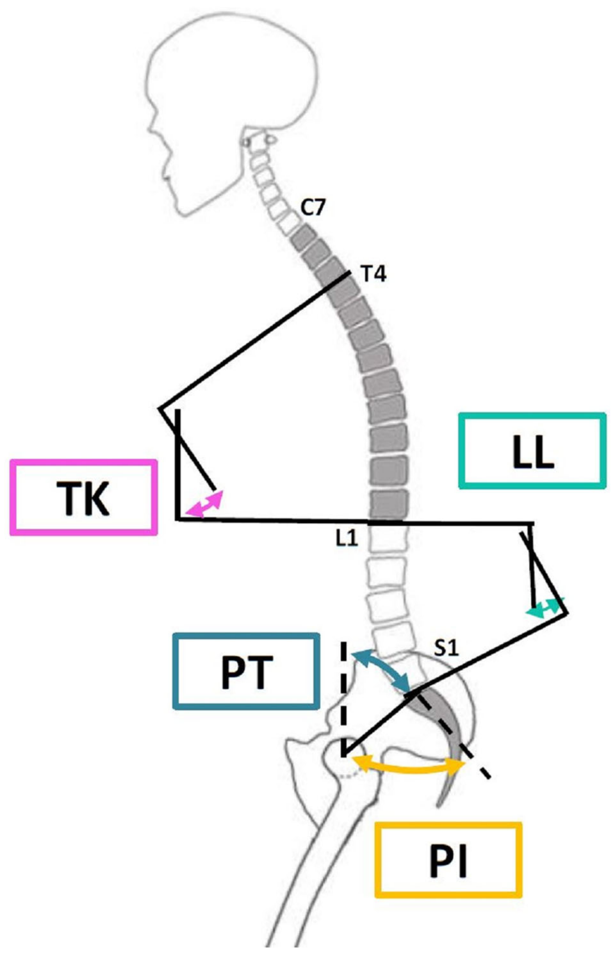

FIGURE 1. *Schematic of sagittal spino-pelvic and regional radiographic parameters, including thoracic kyphosis (TK), lumbar lordosis (LL), sagittal vertical axis (SVA), pelvic tilt (PT), and pelvic incidence (PI).*

variables on time to functional decline, accounting for age, sex, and levels fused. Kaplan-Meier sub-analysis of included patients with available SF-36 data was similarly conducted using the previously published SCB threshold of > 35.1 points.[10] Linear regression assessed the relationship between ODI score and SF-36 outcomes at all study intervals. Statistical significance was set $P < .050$.

RESULTS

Study Sample

Of 412 eligible patients meeting the SCB at 1Y, a total of 166 (40%) surgical ASD patients met inclusion criteria with complete 3-yr ODI data. One eligible patient was lost to follow-up due to death. There were no differences between included patients and patients lost to follow-up in baseline age (57 ± 15 vs 58 ± 17 yr, respectively, $P = .497$), sex (75.3% vs 77.4% female, $P = .623$), CCI (1.48 ± 1.58 vs 1.48 ± 1.52, $P = .961$), 1Y BMI (25.7 ± 5.1 vs 25.9 ± 5.3 kg/m2, $P = .764$), or 1Y ASD-FI scores (1.55 ± 0.87 vs 1.53 ± 0.86, $P = .745$). Surgical factors did not differ between included patients and patients lost to follow-up: levels fused (10.4 ± 4.1 vs 11.2 ± 4.2, $P = .112$), operative time (368 ± 135 vs 351 ± 132, $P = .214$), approach ($P = .528$), and osteotomy utilization (63.9% vs 62.2%, $P = .732$).

TABLE 1. Baseline Comorbidity and Surgical Characteristics of Entire 166 Patient Cohort

Comorbidity	
CCI	1.48 ± 1.55
Anemia	8.4%
Arthritis	38.0%
Depression	16.9%
Diabetes mellitus	6.0%
Heart disease	10.2%
Hypertension	35.5%
Lung disease	2.4%
Osteoporosis	13.3%
Peripheral vascular disease	1.2%
Surgical	
Approach	
Anterior-only	1.8%
Posterior-only	67.5%
Combined	30.7%
Osteotomy	
Any	71.1%
Smith Petersen	60.2%
Three column	69.9%
Levels fused	11.3 ± 4.3
EBL (cc's)	1623 ± 1626
LOS (d)	7.3 ± 3.6
Decompression	55%
Staged procedure	15.1%
BMP-2	42.7%
Allograft	13.3%
Revision after 1-yr	12.7%

VCR = Vertebral Column Resection; EBL = Estimated Blood Loss; LOS = Length of Hospital Stay; BMP-2 = Bone Morphogenic Protein 2.

Cohort Overview

Of the included 166 patients, mean age was 57.3 ± 15.0 yr, mean BMI was 26.7 ± 6.1 kg/m^2, and 75.3% of patients were female. Table 1 describes the comorbidity burden and surgical profile of the overall cohort. Assessed by the SRS-Schwab ASD classification system, all patients showed moderate or severe PT or PI-LL sagittal deformity modifiers at baseline, indicating lumbopelvic deformity. Operative ASD intervention resulted in significant overall baseline to 1Y improvements in sagittal alignment (Table 2). The overall cohort showed significant baseline to 1Y functional improvement, as assessed by ODI score (35.3 ± 16.5-13.6 ± 9.2, $P < .001$). However, compared to

TABLE 2. Univariate Comparison of Baseline and 1Y Radiographic Parameters for all 166 Included Patients

Radiographic parameter	Baseline	1-Yr	P value
PI (°)	54.2 ± 12.9	54.3 ± 12.9	.843
PT (°)	23.3 ± 11.2	20.5 ± 10.5	*** < .001**
PI-LL (°)	13.6 ± 21.6	2.3 ± 14.9	*** < .001**
TK (°)	− 33.2 ± 18.7	42.4 ± 17.1	*** < .001**
C7-S1 SVA (mm)	52.3 ± 67.0	19.9 ± 53.0	*** < .001**
C2-S1 SVA (mm)	69.4 ± 70.6	38.8 ± 56.0	*** < .001**
T1 Slope (°)	27.6 ± 13.2	29.4 ± 14.1	***.033**
TS-CL (°)	18.6 ± 10.9	18.9 ± 9.6	.751
C2-C7 CL (°)	8.1 ± 15.3	9.8 ± 16.5	.074
C2-C7 SVA (mm)	26.8 ± 13.8	27.4 ± 12.6	.415

PI = Pelvic Incidence; PT = Pelvic Tilt; LL = Lumbar Lordosis; TK = Thoracic Kyphosis; SVA = Sagittal Vertical Axis; TS = T1 Slope; CL = Cervical Lordosis. Bolded and Asterisked Values Denote Statistical Significance to $P < .05$.

1Y ODI scores, overall 2-yr postoperative (2Y) and 3Y outcomes were statistically inferior (2Y: 16.6 ± 13.7, $P = .003$; 3Y: 22.0 ± 20.4, $P < .001$). The overall major complication rate was 25.9%, with 9% of these occurring beyond 90-d postoperative.

Durability of Satisfactory Functional Outcomes

Durability of satisfactory functional outcomes following the 1Y interval was 88.6% at 2Y, and 71.1% at 3Y. By 3Y, 48 (28.9%) patients declined in self-reported clinical functionality, deteriorating in ODI score beyond the SCB threshold. As compared to patients who sustained satisfactory functional outcomes beyond 1Y, those who declined in functionality had inferior ODI scores at 2Y (sustained: 11.5 vs declined: 28.3, $P < .001$) and 3Y (11.9 vs 46.7, $P < .001$) study intervals (Figure 2).

Of the 166 included patients, 165 (99%) also had available SF-36 data by the 3Y interval. Mean overall SF-36 physical component scores were 34.9 ± 11.8 at baseline, 45.6 ± 7.4 at 1Y, 43.6 ± 9.9 at 2-yr, and 42.6 ± 10.6 at 3-yr (Figure 3). Overall, 90.3% of patients met the SCB threshold for SF-36 at 1-yr, 81.4% at 2-yr, and 76.4% at 3-yr. Linear regression showed significant relationships between ODI and SF-36 score at baseline ($R^2 = 0.646$), 1-yr ($R^2 = 0.320$), 2-yr ($R^2 = 0.566$), and 3-yr ($R^2 = 305$) intervals (all $P < .001$).

Changes in Sagittal Alignment by Functionality Group

There were no differences in preoperative or 1Y PI-LL, SVA, TS-CL, or TS-CL between patient groups (Table 3). Despite this, patients who deteriorated in functionality beyond 1Y showed significantly greater 1Y to 3Y changes in sagittal alignment: PI-LL (declined: 2.8° ± 6.4 vs sustained: 0.4° ± 5.3, $P = .018$), SVA (15.5 mm ± 40.3 vs 0.6 mm ± 32.9, $P = .022$), TS-CL (7.0° ± 11.0 vs 2.7° ± 8.7, $P = .029$), and cSVA (21.4 mm ± 42.5 vs 3.0 mm ± 32.9, $P = .005$).

Patient and Surgical Factors Associated With Functional Decline

As compared to patients who sustained functional gains beyond 1Y, patients who declined in functionality were significantly older (declined: 64 ± 12 yr vs sustained: 55 ± 15 yr) and more frail (mean ASD-FI: 1.96 ± 0.92 vs 1.39 ± 0.79). Univariate analysis showed a higher baseline comorbidity burden in the functional decline group, including increased rates of lung disease (6.3% vs 0.8%), osteoporosis (22.9% vs 9.3%), hypertension (52.4% vs 28.0%), and heart disease (20.8% vs 5.9%, Table 4). The only surgical factors associated with functional decline after 1Y were posterior-only approach (81.3% vs 61.9%) and reoperation beyond 1-yr of index operation (22.9% vs 8.5%).

Multivariate Predictors of Rapid Functional Decline

Multvariate Cox Proportional Hazards regression analyses, controlling for age, sex, and fusion length, identified lung disease (HR: 4.3, [1.3-15.0], $P = .005$) as a preoperative factor predictive of shorter time to functional decline. Posterior approach (HR: 2.6 [1.2-5.8], $P = .025$) and 1Y frailty (HR: 1.4 [1.1-1.9], $P = .001$) were also predictive of functional decline.

DISCUSSION

The primary goals of surgical ASD correction include neural decompression, restoration of sagittal and coronal balance, and perhaps most importantly, reduction of patient-reported pain and disability. The literature consistently shows ASD-corrective surgery to provide patients with substantial improvements in HRQoL and reductions in patient-reported disability; however, the durability of satisfactory clinical outcomes following ASD-corrective surgery remains under-investigation.[16-18] Of the 166 patients in this study who demonstrated SCB from ASD-corrective surgery by 1Y, 71% maintained satisfactory functional outcomes by the 3Y interval. Furthermore, a number of patient-related factors, including posterior surgical approach, frailty, and comorbidity burden were predictive of rapid functional deterioration. These results have important implications both for preoperative patient counseling and for assessing the value of surgical intervention.

This analysis used the previously published ODI SCB threshold (< 31.3 points) as a benchmark for satisfactory postoperative functional outcomes.[10] In contrast to the minimum clinically important difference—a floor value that defines the smallest change in ODI score reflective of clinical improvement—the SCB threshold serves as a target value for defining postoperative clinical success.[10,19,20] While all patients included in the present study met the SCB threshold at 1Y, 11.4% of patients lost SCB at 2-yr, followed by 17.5% more at 3-yr. Prior reports show stable functional gains following surgical ASD correction, both from 2- to 3-yr postoperative, and from 2- to 5-yr postoperative.[6,7] These studies, however, did not investigate clinical outcomes

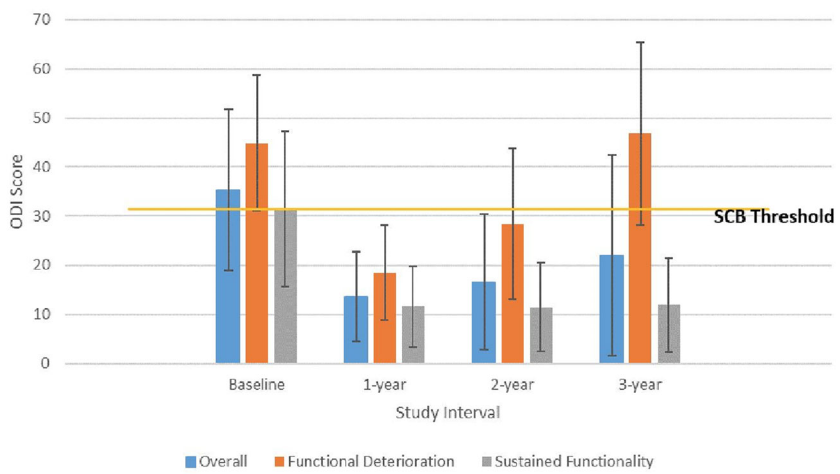

FIGURE 2. *Mean ODI scores overall and within patient cohorts.*

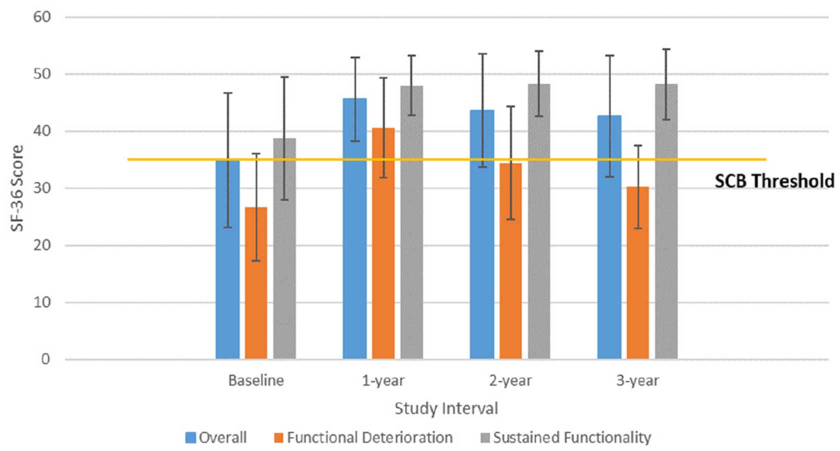

FIGURE 3. *Mean SF-36 scores overall and within patient cohorts.*

in terms of SCB, and included patient populations with lower overall comorbidity burdens and shorter fusions than the present study.

Our multivariate analysis identified comorbidity burden as a predictor of functional decline following surgery. Specifically, after accounting for age, sex, and fusion length, our results showed both preoperative lung disease and increased 1Y frailty as significant predictors of shorter time to functional decline. These results are consistent with previous reports showing lung disease as a potential predictor of adverse outcomes following ASD surgery.[21] To develop a more comprehensive understanding of the relationship between comorbidity burden and functional decline, future research should attempt to disentangle the respective influences of comorbidity burden and postoperative pain levels on functional outcomes following ASD-corrective surgery.

Increased patient frailty has also been associated with inferior outcomes following ASD-corrective surgery, including higher rates of complications, prolonged hospital stay, mortality, and reoperation.[22,23] Interestingly, other research has reported that despite higher preoperative risk stratification scores, frail patients are more likely to meet the SCB threshold for ODI at 2-yr follow-up than nonfrail and severely frail patients.[24] The results of our study suggest that postoperative frailty, rather than preoperative, has a greater bearing on the durability of satisfactory functional outcomes following ASD surgery.

It is important to note that the functional decline observed in our study appeared to be associated with patient age and

TABLE 3. Comparison of Radiographic Parameters Between Patients who Sustained Satisfactory Functional Outcomes Beyond 1Y, and Patients who Deteriorated in Functionality

		Sustained functionality (n = 118)	Functional deterioration (n = 48)	*P* value
PT (°)	BL	22.3 ± 11.4	25.3 ± 10.3	.093
	1Y	20.0 ± 10.8	21.7 ± 9.8	.342
	3Y	20.8 ± 10.8	24.1 ± 9.6	.093
	Δ1Y-3Y	1.0 ± 3.9	1.4 ± 4.3	.663
PI-LL (°)	BL	11.5 ± 21.3	18.4 ± 21.5	.058
	1Y	2.1 ± 15.2	2.6 ± 14.0	.854
	3Y	2.1 ± 14.6	6.0 ± 15.2	.122
	Δ1Y-3Y	0.4 ± 5.3	2.8 ± 6.4	*.018
TK (°)	BL	− 31.8 ± 18.6	− 36.2 ± 18.1	.054
	1Y	− 40.3 ± 17.8	− 46.5 ± 14.8	*.035
	3Y	− 41.1 ± 17.7	− 48.1 ± 14.2	*.012
	Δ1Y-3Y	− 0.8 ± 6.8	− 0.6 ± 6.3	.651
C7-S1 SVA (mm)	BL	45.3 ± 66.5	66.1 ± 67.0	.077
	1Y	18.8 ± 55.3	28.2 ± 53.4	.319
	3Y	18.3 ± 50.1	44.7 ± 58.9	*.007
	Δ1Y-3Y	0.6 ± 32.9	15.5 ± 40.3	*.022
C2-S1 SVA (mm)	BL	61.2 ± 69.4	88.5 ± 72.5	*.039
	1Y	40.0 ± 57.3	45.6 ± 55.0	.428
	3Y	41.1 ± 55.0	73.8 ± 65.8	*.003
	Δ1Y-3Y	3.0 ± 32.9	21.4 ± 42.5	*.003
T1 slope (°)	BL	25.9 ± 12.9	31.1 ± 13.3	*.022
	1Y	28.4 ± 14.6	32.1 ± 12.1	.124
	3Y	31.0 ± 14.3	37.4 ± 12.8	*.009
	Δ1Y-3Y	2.7 ± 7.5	5.2 ± 7.5	*.036
TS-CL (°)	BL	18.2 ± 10.4	20.3 ± 12.0	.312
	1Y	18.6 ± 10.0	18.5 ± 8.9	.941
	3Y	20.7 ± 9.4	26.7 ± 15.6	*.022
	Δ1Y-3Y	2.7 ± 8.7	7.0 ± 11.0	*.029
C2-C7 CL (°)	BL	6.4 ± 14.1	11.4 ± 17.1	.078
	1Y	9.3 ± 17.1	13.1 ± 14.5	.118
	3Y	10.0 ± 16.8	10.4 ± 16.5	.893
	Δ1Y-3Y	0.3 ± 8.5	− 1.8 ± 11.0	.220
cSVA (mm)	BL	26.8 ± 13.9	28.0 ± 15.2	.717
	1Y	28.1 ± 12.9	26.9 ± 11.4	.591
	3Y	27.8 ± 11.7	32.8 ± 16.0	.087
	Δ1Y-3Y	0.4 ± 7.5	5.0 ± 8.3	*.005

Alignment was Compared at Baseline (BL), 1-yr (1Y), 2-yr (2Y), and 3-yr (3Y) Follow-up Intervals. Change in Alignment Between 1Y to 3Y (Δ1Y-3Y) Were Also Assessed. PI = Pelvic Incidence; PT = Pelvic Tilt; LL = Lumbar Lordosis; TK = Thoracic Kyphosis; SVA = Sagittal Vertical Axis; TS = T1 Slope; CL = Cervical Lordosis. Asterisked Values Denote Statistical Significance to $P < .05$.

TABLE 4. Comparison of Baseline Patient Factors and Surgical Factors Between Patients who Sustained Satisfactory Functional Outcomes Beyond 1Y, and Patients who Deteriorated in Functionality

	Sustained functionality (n = 118)	Functional deterioration (n = 48)	*P* value
Baseline patient factors			
Age (yr)	54.7 ± 15.5	63.8 ± 11.5	* < .001
Sex (% female)	78.8%	66.7%	.100
1-yr BMI (kg/m^2)	24.9 ± 4.3	28.0 ± 6.5	*.014
ASD Frailty index	1.39 ± 0.79	1.96 ± 0.92	* < .001
Comorbidity burden			
CCI	1.08 ± 1.33	2.46 ± 1.64	* < .001
Anemia	10.2%	4.2%	.355
Arthritis	28.8%	60.4%	* < .001
Depression	13.6%	25.0%	.074
Diabetes mellitus	4.2%	10.4%	.155
Heart disease	5.9%	20.8%	*.004
Hypertension	28.0%	52.4%	*.001
Lung disease	0.8%	6.3%	.073
Osteoporosis	9.3%	22.9%	*.019
PVD	0.0%	4.2%	.082
Surgical factors			
Approach			
Anterior	1.7%	2.1%	1.000
Posterior	61.9%	81.3%	*.016
Combined	36.4%	16.7%	*.012
Osteotomy			
Any	61.9%	68.8%	.402
Smith Petersen	61.0%	58.3%	.749
Three column	69.5%	70.8%	.864
Levels fused	11.1 ± 4.4	11.5 ± 4.0	.606
EBL (cc's)	1389 ± 1180	2190 ± 2302	*.021
LOS (d)	7.0 ± 3.4	8.0 ± 3.8	*.024
Decompression	51.70%	64.40%	.130
Staged procedure	16.90%	10.40%	.286
BMP-2	41.50%	45.80%	.611
Allograft	12.70%	14.60%	.747
Revision after 1-yr	8.50%	22.90%	*.011

Asterisked Values Denote Statistical Significance to $P < .05$. ASD = Adult Spinal Deformity; CCI = Charlson Comorbidity Index; PVD = Peripheral Vascular Disease; VCR = Vertebral Column Resection; EBL = Estimated Blood Loss; LOS = Length of Hospital Stay; BMP-2 = Bone Morphogenic Protein 2.

concomitant decline in patient health, rather than recurrence of ASD. Although we observed statistically significant differences between patient groups in 1Y to 3Y changes of spinopelvic alignment, both patient groups showed 3-yr PT (declined: 24.1°, sustained: 20.8°), PI-LL (declined: 6.0°, sustained: 2.1°), and SVA (declined: 44.7 mm, sustained: 18.3 mm) alignment consistent with previously published thresholds for nonpathologic or nonsevere deformity.[25] Thus, although 29% of patients in our analysis demonstrated functional deterioration between 1- and 3-yr follow-up intervals, there was little evidence to suggest that this decline was related to deformity progression. Still, differences in baseline alignment between patient functionality groups may indicate that, as expected, more severe deformity at baseline may be associated with less durable functional outcomes. These results reinforce previous studies demonstrating the appreciable long-term radiographic benefit of ASD-corrective surgery for patients with moderate to severe deformity.[26,27]

Limitations

Despite the strengths of our multicenter study design and complete 3-yr clinical follow-up, our analysis appreciates a number of limitations. First, it is important to note that this study utilizes absolute thresholds for SCB, as opposed to net or proportional improvements in HRQoL outcomes. In using an absolute SCB threshold, the present study sought to avoid the pitfalls associated with the ceiling effect; namely, that patients who start with low-to-moderate disability typically cannot improve as much as patients that start with severe disability. As this study intended to look at the durability of good outcomes for patients that experienced functional gains following surgery, we opted to use an absolute SCB threshold, as opposed to net changes or proportional improvements in HRQoL scores; however, the upshot of this methodology is a potentially less sensitive means of detecting worsening in functional outcomes.

Another limitation lies in the differences between baseline radiographic factors for those categorized with sustained functionality vs those who functionally deteriorated. Many of the factors that classify an ASD patient were more severe at baseline in those who deteriorated, calling into question the effect that they may have been more susceptible to functionally deteriorating in the future. The present analysis assumes that complications occurring before the 1Y interval had little effect on achieving a satisfactory functional outcome. Complications occurring beyond the 1-yr interval may have affected the durability of satisfactory functional outcomes; however, the database used in the present analysis does not include temporal complication data beyond 90 d postoperative. As such, we are unable to investigate effects that complications occurring beyond 90-d postoperative have on achieving functional outcomes. Additionally, the retrospective study design coupled with the 3-yr follow-up inclusion requirement may have resulted in a biased patient population with a particularly high comorbidity burden.

Finally, the SCB threshold used in our analysis was developed in a population of lumbar fusion patients, and is not specific for spinal deformity patient populations. We believe it is important to note that severe ASD has been shown to significantly impair HRQoL, while patients undergoing short-segment lumbar fusion may be able to complete routine daily activities with some level of low-back disability. As such, the 31.3 point threshold used in this study may be more rigorous than is necessary to capture SCB for ASD patients, as smaller clinical improvements are likely to have a larger impact on HRQoL for individuals with severe deformities. As a result, the results of our study may actually underestimate the proportion of ASD patients showing SCB following surgery. Despite these shortcomings, in showing the duration satisfactory functional outcomes following ASD-corrective surgery, the results of our study serve as a valuable tool to better inform patient counseling regarding expectations following surgery.

CONCLUSION

Initial satisfactory ODI and SF-36 outcomes following ASD-corrective surgery were maintained by 71% and 76% of patients, respectively, at the 3-yr follow-up interval. Postoperative recurrence of deformity did not appear to play a strong role in influencing functional decline, as ASD-corrective surgery was effective at preventing disease progression by the 3Y interval. Rather, posterior surgical approach, preoperative lung disease, and 1Y patient frailty were all significant predictors of less durable functional outcomes. As successful surgical management of ASD should entail durable clinical outcomes, the results of this study can be used to better assess the value of surgical intervention, to direct future cost-effectiveness studies, and to better inform preoperative patient counseling.

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