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CASE SERIES

Do readmissions and reoperations adversely affect patient-reported outcomes following complex adult spinal deformity surgery at a minimum 2 years postoperative?

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Abstract

Background Unplanned readmissions and reoperations are known to be associated with undesirable costs and potentially inferior outcomes in complex adult spinal deformity (ASD) surgery. A paucity of literature exists on the impact of readmissions/reoperations on patient-reported outcomes (PRO) in this population.

Methods Consecutively treated adult patients who underwent complex ASD surgery at a single institution from 2015–2018 and minimum 2-year follow-up were studied. Demographics/comorbidities, operative factors, inpatient complications, and postoperative clinical and patient-reported outcomes (SRS-22r, ODI) were assessed for those with and without readmission/reoperation.

Results 175 patients (72% female, mean age 52.6 ± 16.4) were included. Mean total instrumented/fused levels was 13.3 ± 4.1, range 6–25. The readmission and reoperation rates were 16.6% and 12%, respectively. The two most common causes of reoperation were pseudarthrosis (5.1%) and PJK (4.0%). Predictors for readmission within 2 years following surgery included pulmonary, cardiac, depression and gastrointestinal comorbidities, along with performance of a VCR, and TLIF. At 2 years postoperatively, those who required a readmission/reoperation had significant increases in SRS and reductions in ODI compared to 1-year and preoperative values. Inpatient complications did not negatively impact 2-year PRO's. The 2-year MCID in PROs was not significantly different between those with and without readmission/reoperation.

Conclusion Complex ASD surgery carries risk, but the vast majority can achieve MCID (SRS-86.4%, ODI-68.2%) in PROs by 2 years. Importantly, even those with inpatient complications and those who required unplanned readmission/reoperation can improve PROs by 2-year follow-up compared to preoperative baseline and 1-year follow-up and achieve similar improvements compared to those who did not require a readmission.

Level of evidence III.

Keywords Adult spine surgery · Spinal deformity · Readmissions · Reoperations · Complications

Introduction

Improving clinical outcomes and reducing excessive costs are especially relevant in providing value-based care for complex adult spinal deformity (ASD) patients. According to current literature, complications after ASD surgery are frequent in the early (24–36%) and late (11–15%) postoperative settings [1]. These include medical and surgery-related complications (pseudarthrosis, proximal junctional kyphosis (PJK), wound complications, DVT/PE, infection, pneumonia, ileus) often resulting in costly readmissions which may be avoidable [2–7]. This has led to a number of studies investigating risk factors for unplanned readmissions, but much of this data is limited by a lack of spine-specific factors and rigorous complication data, single-surgeon data, and short-term follow-up periods [8–12].

In recent decades, there has been a growing focus on patient-reported outcomes (PROs) in ASD patients [13]. A multicenter database study found that ASD operative candidates scored lower in every domain of the Short Form-36 Health-Survey compared to other chronic conditions

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(arthritis, chronic lung disease, diabetes, and congestive heart failure) [14]. Although it is well known that surgery can significantly reduce disability, pain, and improve overall quality of life compared to nonoperative management, the impact of unplanned readmissions and reoperations on PROs in the complex ASD population remains unclear [15–22].

Compared to prior literature, our study focuses on complex ASD surgical patients and evaluates the clinical data and PROs with a minimum 2-year postoperative follow-up. The purpose of this study was to assess the impact of readmissions and reoperations on PROs. In addition, we sought to provide an in-depth analysis on underlying reasons and risk factors for readmissions occurring anytime in the first 2 years following surgery.

Materials and methods

In this study, we retrospectively reviewed a prospectively accrued data set of a consecutive group of complex ASD (≥ 18 years) surgeries performed between 2015 and 2018. These patients were treated by three experienced spinal deformity surgeons at a single-institution. "Complex ASD" cases had a primary or revision diagnosis of ASD and underwent ≥ 6-level fusion surgery with either posterior column osteotomy (PCO), pedicle subtraction osteotomy (PSO), vertebral column resection (VCR), pelvic fixation, and/or interbody fusion (e.g., TLIF). Common diagnoses included adult idiopathic scoliosis, degenerative lumbar scoliosis, congenital spine deformity, kyphoscoliosis, fixed sagittal imbalance, fixed coronal imbalance, flat back deformity, neuromuscular scoliosis, and Scheuermann's kyphosis (Table 1). Patients were excluded if they had a diagnosis of spinal trauma, active infection, and spinal tumor. The minimum follow-up was 2 years after the index hospital discharge date. This study was approved by the institutional review board at Columbia University Medical Center.

Table 1 Common diagnoses for the primary adult spinal deformity population, $N = 175$

Diagnoses	#	%
Adult idiopathic scoliosis	90	51.4
Fixed sagittal imbalance	74	42.3
Kyphoscoliosis	45	25.7
Fixed coronal imbalance	53	30.3
Degenerative lumbar scoliosis	22	12.6
Double major curve	15	8.6
Adolescent idiopathic scoliosis	6	3.4
Congenital/juvenile thoracic scoliosis	5	2.9
Flat back deformity	4	2.3
Scheuermann's kyphosis	4	2.3
Neuromuscular scoliosis	3	1.7

Demographics included sex, age, American Society of Anesthesiologists grade (ASA), and Body Mass Index (BMI, kg/m^2). Medical comorbidities included cardiac (myocardial infarction, hypertension, hyperlipidemia, coronary artery disease), pulmonary (asthma, chronic obstruction pulmonary disease, obstructive sleep apnea, prior pneumonia), gastrointestinal (GI) (gastroesophageal reflux disease/GERD, peptic ulcer disease, ulcerative colitis, celiac disease), osteoporosis/osteopenia, diabetes, hypothyroidism, anemia, depression, history of deep vein thrombosis/pulmonary embolism (DVT/PE), and history of cancer (non-spine tumor). Operative variables included total instrumented levels (TIL), pelvic fixation, osteotomy type (PCO, PSO, VCR), anterior lumbar interbody fusion (ALIF), oblique lumbar interbody fusion (OLIF), transforaminal lumbar interbody fusion (TLIF), estimated blood loss (EBL), operative/anesthesia durations, and prior spine surgery.

Intraoperative/postoperative complications, which occurred during the same inpatient stay, included intraoperative dural tear, intraoperative motor/sensory loss, GI (ileus, nausea/vomiting), cardiac (cardiac/respiratory arrest, lower extremity edema, hypovolemic shock, pericardial effusion), pulmonary (respiratory distress/failure, pneumonia, pleural effusion), DVT/PE, hyponatremia, neurologic (motor deficit), infection (skin, urinary tract infection), acute kidney injury, and postoperative red blood cell transfusion.

Any readmission/reoperation within 2 years after the index hospital date of discharge was assessed. Reasons for readmission were reviewed carefully in each chart review by an orthopedic surgeon independent of the primary treatment team. χ^2/Fisher's exact test and t-tests/ANOVA were used for categorical and continuous variables, respectively. To determine the independent predictors for the outcomes of interest, stepwise multivariate logistic regression analysis was used. Statistical significance was defined as p value < 0.05. The C-statistic and Hosmer–Lemeshow (HL) value were used to measure concordance and goodness-of-fit for the final models. SAS Studio Version 3.4 (SAS Institute Inc, Cary, NC) was used for all statistical analyses.

PROs that included both the Scoliosis Research Society-22R (SRS-22R) and the Oswestry Disability Index (ODI) were recorded in both the preoperative and up to the 2-year postoperative period. For those with readmissions, the most recent PRO data were taken after the readmission discharge date. Several prior studies have demonstrated that both the SRS-22R and the ODI are reliable, valid, and responsive to change in patients undergoing adult spinal deformity surgery [23–25]. There are various proposed methods to calculate the minimum clinically important

difference (MCID) for PRO's. In this study, we used a difference of 0.5 times the standard deviation, which has been used in prior literature and known to be equivalent to 1-standard error of measurement for a reliability of 0.75 [26, 27].

Source of funding

No source of funding was provided for this study.

Results

A total 175 consecutive patients met inclusion criteria. The mean follow-up ± standard deviation was 2.5 ± 0.5 years (range 2–3.8 years). Percent follow-up for the 2-year postoperative period was 71.3%. The mean age was 52.6 ± 16.4 years and 72% were female. The two most common preoperative diagnoses included adult idiopathic scoliosis (51.4%) and fixed sagittal imbalance (42.3%) (Table 1). 40.6% had a prior spine surgery. The mean TIL was 13.3 ± 4.1 (range 6–25), with the majority of patients having pelvic fixation (76.6%), PCOs (84.6%, mean 5.4/patient), and TLIF (69.1%, mean 1.4/patient). A smaller number of patients had a 3-column osteotomy (3CO) [13.7% VCR (8.0%; mean 1.5/patient), PSO (5.7%; mean 1.0/patient)] and ALIF/OLIF (2.3%; mean 1.5/patient). Overall mean operative time was 473 ± 137 min with mean EBL of 1324 (24.6%) ± 822 mL (16.4%) (Table 2).

Table 2 Operative characteristics of ASD patients

	All
Total instrumented levels	
Mean (standard deviation)	13.3 (4.1)
Range	6–25
Pelvic fixation, % patients	76.6%
PCO	
%patients	84.6%
Mean # per patient w PCO	5.4 (2.8)
PSO	
%patients	5.7%
Mean # per patient with PSO	1.0
VCR	
%patients	8%
Mean # per patient with VCR	1.5 (0.5)
TLIF	
%patients	69.1%
Mean # per patient with PLIF	1.4 (0.6)
ALIF/OLIF	
%patients	2.3%
Mean # per patient with ALIF/OLIF	1.5 (0.2)
Operative time (min)	473 (137)
Anesthesia time (min)	571 (139)
Estimated blood loss (mL)	1324 (822)
Estimated blood volume (%)	24.6 (16.4)

The 2-year readmission and reoperation rates were 16.6% and 12.0%, respectively (Table 3). The median number of days after index discharge date resulting in a readmission and reoperation were 173 days (range 6–716) and 227 days (range 16–716), respectively. Eight patients who were readmitted did not require a reoperation. These readmissions without reoperation were due to headache from a dural tear (1.7%), muscle spasms (0.6%), abdominal pain (0.6%), and poorly controlled pain (1.7%). Reoperations were due to pseudarthrosis (5.1%), PJK (4.0%), wound complication (2.3%), upper and/or lower extremity weakness (2.3%), prominence over incision (1.1%), postoperative fall (1.1%), radiculopathy (0.6%) (Table 4). For the two patients with prominence over incision, the wound closure was well healed; however, both had prominent spinous processes causing localized pain requiring excision.

In the multivariate analysis for 2-year readmissions, GI comorbidity (OR: 12.6, 95%CI 3.1–50.7), TLIF (OR: 10.1, 95%CI 2.0–50.6), VCR (OR: 8.8, 95%CI 1.7–44.6), pulmonary comorbidity (OR: 5.4, 95%CI 1.7–17.1), depression (OR: 4.4, 95%CI 1.4–13.8), and cardiac comorbidity (OR: 3.3, 95%CI 1.2–9.2) were independent risk factors and demonstrated good model performance (C-statistic = 0.88; HL = 0.1). Of note, 82.4% of the GI complications were in patients with a history of GERD, and 85.3% of the pulmonary comorbidities were in patients with asthma/COPD. Prior spinal surgery increased readmission risk by 2.5-fold, but was not statistically significant ($p = 0.097$). Although age, PSO, operative time, postoperative transfusion, and postoperative inpatient neurologic complications were significant in the bivariate analysis, they were not statistically significant factors in the multivariate analysis (Tables 5, 6).

Inpatient complications (intraoperative and postoperative) were assessed to determine potential differences in PROs in those with and without complications (Table 7). Patients

Table 3 Breakdown of readmissions and follow up after ASD surgery

	90 days	1 year	2 years
# Readmitted	17	23	29
# Reoperations	12	17	21
# Eligible for read/reop	227	220	175
% Readmitted	**7.5%**	**10.4%**	**16.6%**
%Reoperations	**5.3%**	**7.7%**	**12.0%**
% Follow up	92.3%	89.5%	71.3%

Bold value indicates the category headings

Table 4 Top complications requiring readmission (patients had ≥ 1 complication)

	N	%	Median days after discharge (range)
2-year readmission *includes reoperations	29	16.6	173 (6 to 716)
2-year reoperation	21	12.0	227 (16 to 716)
Pseudoarthrosis	9	5.1	412 (56 to 659)
Proximal junctional kyphosis	7	4.0	366 (56 to 608)
Other pain requiring admission	5	2.9	173 (6 to 602)
Wound complication	4	2.3	25 (16 to 50)
Unexplained extremity weakness	4	2.3	200 (76 to 246)
Dural tear	3	1.7	6, 28, 28
Prominence of incision	2	1.1	343, 716
Postoperative fall	2	1.1	383, 608
Lumbar radiculopathy	1	0.6	48

with "any" inpatient complication had worse ODI scores at baseline and at 1-year postoperative. However, no significant differences were seen by 2 years postoperative. For SRS, no significant differences were seen at baseline, 1 year, and 2 years postoperative for either any inpatient complications, intraoperative complications, or inpatient-postoperative complications. 2 patients required revision surgery for lower extremity pain/weakness, but neither sustained permanent neurologic deficit. The 2-year MCID PROs (SRS and ODI) were not significantly different between those with and without inpatient complications (Table 8).

2 years after the index surgery, 86.4% and 68.2% of all patients reached MCID for SRS and ODI, respectively. At 1-year follow-up, patients who did not require a readmission had significantly better PROs compared to preoperative values (baseline PRO: SRS 59.9, ODI 33.4; 1-year PRO: SRS 85.9, ODI 18.0; $p < 0.001$) as well as those who required either a readmission (1-year SRS 78.5, $p < 0.001$; 1-year ODI 20.3; $p < 0.001$) or reoperation (1-year SRS 71; $p < 0.001$; 1-year ODI 23.8; $p < 0.001$) (Table 9). At 2 years postoperative, those who required a readmission had significant increases in SRS and reductions in ODI (2-year: SRS 90.6, ODI 15.5) compared to 1-year (SRS 78.5, ODI 20.3; $p < 0.001$) and preoperative values (SRS 60.1, ODI 44.9; $p < 0.001$). A similar significant difference was seen for revised patients as well (2-year Revised: SRS 90.9, ODI 13.4; 1-year Revised: SRS 71, ODI 23.8; $p < 0.001$; Baseline: SRS 56.6, ODI 45.6; $p < 0.001$). At 2 years postoperative, a substantial number of readmitted patients achieved MCID for SRS (100%) and ODI (83.3%). The same was seen for revised cases: MCID SRS 100%; ODI 85.7%. For those without readmission/reoperation, MCID was achieved in 83.4% for SRS and 64.9% for ODI. No statistically significant differences between those with and without readmission/reoperation were observed for 2-year PRO's: SRS (readmission: 90.6 vs. non-readmission: 87.4; $p = 0.586$) or ODI (readmission: 15.5 vs. 16.9; $p = 0.834$) | SRS (reoperation: 90.9 vs. non-reoperation: 87.4; $p = 0.585$) or ODI (reoperation: 13.4 vs. non-reoperation: 16.9; $p = 0.583$).

Significant improvements occurred in each SRS domain score, but the largest changes occurred in the pain and self-image domains. Similarly, the largest significant changes for ODI occurred in pain, standing, sleeping, and traveling domains (Figs. 1, 2). By 2 years postoperative, patients who experienced a transient complication versus a permanent complication had a significantly higher total SRS score (89.2 vs. 67.7; $p = 0.016$), higher MCID percentage (85.7% vs. 67.7%; $p < 0.001$), and a higher ODI MCID (66.7% vs. 15.4%; $p = 0.001$) (Table 10).

The findings of this study may be best represented by patient-AB, a 69-year-old female with severe thoracolumbar posttraumatic osteoporotic kyphosis (> 100°) (Fig. 3). Medical comorbidities included depression, osteoporosis, and GERD. Preoperatively, she suffered from severe back pain and difficulty breathing and eating because of her severe kyphotic posture. Her preoperative SRS/ODI was 69/40. Surgery involved posterior spinal instrumented fusion from T1-sacrum/ilium, multiple PCOs (8), T11 VCR, and L5-S1 TLIF, with an EBL of 800 mL, and operative time of 545mins(Fig. 3). Her hospital course was complicated by pleural effusion and acute blood loss anemia requiring blood transfusion, and a 9-day LOS. Post-discharge, she otherwise did well, until 2 years postoperative when she complained of new onset lower back pain with X-rays demonstrating rod fractures at L4-5(Fig. 4). She was readmitted to undergo revision instrumentation from L1-pelvis with repair of the L4-5 pseudarthrosis (Fig. 4). At the most recent follow-up visit (2 years after revision surgery), she was doing very well without major issues. Her postoperative SRS/ODI scores after revision at latest follow-up were 100/18, respectively.

Table 5 Patient clinical characteristics by readmission

	1 year			2 years		
	No	Yes		No	Yes	
N	197	23	*p* value	146	29	*p* value
Female (%)	68	69.6	0.88	70.6	79.3	0.337
Age, Mean (standard deviation, sd)	50.1 (17.7)	57.3 (16.5)	0.063	51.3 (16.7)	59.6 (13.5)	**0.013**
Age (%)						
≤40	10.2	4.4	0.176	25.3	10.3	0.114
41 to 50	27.9	17.4		10.3	3.5	
51 to 60	25.4	21.7		27.4	21.1	
61 to 70	31	39.1		31.5	51.7	
≥71	5.6	17.4		5.5	10.3	
American society of anesthesiologists > 2 (%)	25.9	43.5	0.075	28.1	34.5	0.488
Body Mass Index > 30 kg/m^2 (%)	45.7	60.9	0.168	49.3	51.7	0.813
Comorbidities (%)						
Cardiac	35	56.5	**0.044**	34.3	62.1	**0.005**
Pulmonary	14.7	39.1	**0.003**	15.8	37.9	**0.006**
Gastrointestinal	6.1	26.1	**0.001**	4.8	34.5	**< 0.001**
Osteoporosis/osteopenia	22.3	21.7	0.948	23.3	24.1	0.921
Diabetes	3.1	4.4	0.736	3.4	6.9	0.384
Hypothyroidism	12.7	17.4	0.528	15.1	17.2	0.767
Anemia	3.1	4.4	0.736	2.7	0	0.367
Prior transient ischemic attack/stroke	0.51	0	0.732	0.68	0	0.655
Anxiety	16.8	21.7	0.549	18.5	24.1	0.483
Depression	17.8	39.1	**0.015**	17.1	41.4	**0.004**
Deep vein thrombosis/pulmonary embolism	2.5	13	**0.011**	2.7	6.9	0.261
History of cancer	7.1	17.4	0.0886	8.9	10.3	0.806
Operative characteristics						
Total instrumented level, mean (sd)	13.3 (3.9)	13.8 (4.1)	0.583	13.2 (4.1)	14.3 (4.2)	0.185
PCO, mean (sd)	4.7 (3.1)	3.9 (3.0)	0.242	4.7 (3.3)	4.2 (2.7)	0.448
PCO, %patients	85.3	82.6	0.734	84.3	86.2	0.79
PSO, %patients	5.6	8.7	0.549	4.11	13.8	**0.040**
VCR, %patients	6.6	17.4	0.067	6.2	17.2	**0.045**
ALIF/OLIF, %patients	2.6	0	0.627	2.1	7.1	0.201
TLIF, %patients	63.5	82.6	0.068	65.8	86.2	**0.029**
Pelvic fixation, %patients	72.1	82.6	0.281	74.7	86.2	0.18
Estimated blood loss, mean (sd)	1300 (812)	1479 (854)	0.32	1288 (826)	1507 (804)	0.191
Operative time, mean (sd)	463 (133)	554 (119)	**0.002**	459 (137)	548 (119)	**0.001**
Anesthesia time, mean (sd)	558 (135)	648 (123)	**0.003**	556 (137)	651 (123)	**< 0.001**
Prior spine surgery, %patients	36.6	52.2	0.144	37.7	55.2	0.08
Postoperative inpatient complications						
Cardiac	10.7	4.4	0.34	9.6	10.3	0.9
DVT/PE	2.5	4.4	0.614	2.7	3.5	0.834
Gastrointestinal	3.6	0	0.358	4.8	0	0.229
Hyponatremia	1	0	0.627	0.68	0	0.655
Neurologic	0	4.4	**0.003**	0	3.5	**0.024**
Infection	0.5	0	0.732	0.68	0	0.655
Pulmonary	8.6	8.7	0.992	7.5	13.8	0.272
Renal	2	4.4	0.48	2.7	3.5	0.834
Postoperative transfusion	56.4	82.6	**0.015**	58.2	79.3	**0.033**
Length of stay, mean (sd)	7.3 (6.4)	11.4 (11.9)	**0.009**	7.0 (4.7)	8.5 (8.3)	0.189

Table 5 (continued)

Bold value indicates statistical significance

Table 6 Independent predictors for 2-year readmissions after complex ASD Surgery (C-stat = 0.876, HL = 0.1)

Independent risk factors	Odds ratio	95% confidence interval		*p* value
GI comorbidity	12.6	3.1	50.7	**< 0.001**
TLIF	10.1	2.0	50.6	**0.005**
VCR	8.8	1.7	44.6	**0.008**
Pulmonary comorbidity	5.4	1.7	17.1	**0.004**
Depression	4.4	1.4	13.8	**0.012**
Cardiac comorbidity	3.3	1.2	9.2	**0.025**
Prior spine surgery	2.5	0.9	7.1	0.097
Hypothyroidism	0.4	0.1	1.7	0.224

Table 7 Intraoperative and inpatient postoperative complications *patients had ≥ 1 complication

	#	%
Any inpatient complication	125	71.4
Intraoperative complication	54	30.9
Dural tear	41	23.4
Motor/sensory loss	13	7.4
Inpatient postoperative complication	114	65.1
Postoperative transfusion	108	61.7
Cardiac	17	9.7
Pulmonary	15	8.6
Gastrointestinal	7	4.0
DVT/PE	5	2.9
Renal	5	2.9
Infection	2	1.1
Hyponatremia	1	0.6
Return to operating room	2	1.1
Neurologic	2	1.1

Discussion

ASD is an increasingly common condition that is known to cause substantial pain and disability. Corrective surgery can improve health-related quality of life (HRQoL) outcomes; however, complications still occur requiring unplanned readmissions. Several large multicenter studies have reported on ASD outcomes, but there remains a paucity of literature on the impact of postoperative complications on PROs [28–30]. Furthermore, ASD patients are often defined by > 2 spinal fusion levels and/or radiographic parameters [6, 8, 31–33]. Within these cohorts, patients may undergo a range of procedures with more complex ones [e.g., extended fusions (≥ 6), 3COs] at greater risk for significant complications. The purpose of this study was to examine the impact of reoperation/readmission on HRQoL for complex ASD patients defined as those who had a minimum 6-level spinal fusion. We hypothesized that patients who experienced treatable postoperative medical or surgical complications would show significant improvement in HRQoL by 2 years despite the need for readmission/reoperation.

Based on our single-institutional analysis, the overall 2-year readmission (16.6%) and reoperation (12%) rates were relatively low given the surgical complexity involved [34]. The majority of reoperations were for pseudarthrosis (5.1%) and PJK (4%). By 2 years postoperative, the majority of patients reached MCID for SRS (86.4%) and ODI (68.2%). Patients who did not require a readmission had significantly higher PROs compared to preoperative values and to those who required a readmission or reoperation at 1-year follow-up. Those who required a readmission had significant increases in SRS and reductions in ODI at 2 years compared to 1-year and preoperative baseline values. For readmitted patients, the main drivers for improvement in the SRS-22r from 1 to 2 years were the pain (+ 1.0; $p < 0.001$) and the self-image (+ 0.7; $p < 0.001$) domains. In regards to the ODI scores, the main drivers of change from 1 to 2 years were pain (− 0.5; $p = -0.022$), standing (− 0.7; $p = 001$), and sleeping (− 0.5; $p = 0.026$). The magnitude of the change appears small, but a single point can mean the difference between someone who could stand "as long as I want with extra pain" versus "pain prevents me from standing for more than 1 h." Finally, TLIF was also found to be associated with readmission in the multivariate analysis (OR: 10.1, 95%CI 2.0–50.6). This could potentially be explained by the significantly higher rate of intraoperative complications associated with TLIFs (TLIF: 35.5% vs. No TLIF: 20.4%, $p = 0.045$) and specifically intraoperative durotomies (TLIF: 28.9 vs. No TLIF: 11.1, $p = 0.01$). Although there were higher rates for pseudarthrosis (8.3 vs 7.4, $p = 0.847$), postop extremity weakness (2.5 vs. 1.9, $p = 0.798$), pain requiring readmission (4.1 vs. 3.7, $p = 0.894$), wound complications (2.5% vs. 1.9, $p = 0.798$), and implant failure (5.0 vs. 3.7, $p = 0.714$), these were not statistically significant. Nearly every TLIF was performed with pelvic fixation (94.2%). Those with TLIF and pelvic fixation had a lower rate of pseudarthrosis (8.8% vs. 15%; $p = 0.385$) and higher rate of PJK (6.1% vs. 0%; $p = 0.499$) than those with pelvic fixation alone. However, these differences were also not statistically significant.

Few prior studies directly examined the impact of complications on PROs in the complex ASD population, and

Table 8 Patient reported outcomes by inpatient complications

	Any inpatient complication			Intraoperative complications			Inpatient postoperative complications		
	No	Yes	*p* value	No	Yes	*p* value	No	Yes	*p* value
SRS									
Baseline	56.3 (33.4)	61.1 (16.1)	0.284	61.0 (25.1)	57.7 (12.6)	0.413	57.7 (31.0)	60.9 (16.4)	0.452
1 year	88.7 (22.9)	83.7 (15.3)	0.266	87.2 (17.7)	80.3 (16.0)	0.08	86.7 (21.3)	84.1 (15.6)	0.533
2 years	93.8 (9.3)	86.2 (16.4)	0.146	90.2 (14.7)	83.8 (15.9)	0.169	92.3 (10.2)	86.1 (16.8)	0.206
2 year MCID	66.7%	91.4%	0.054	82.1%	93.8%	0.281	75.0%	90.6%	0.179
ODI									
Baseline	27.1 (20.1)	38.3 (18.8)	***0.005***	32.0 (19.9)	42.4 (17.4)	**0.004**	28.3 (19.7)	38.5 (19.0)	**0.007**
1 year	9.2 (9.5)	21 (17.9)	***0.006***	16.2 (16.5)	22.2 (17.9)	0.119	11.7 (11.4)	21.0 (18.3)	**0.021**
2 years	11.5 (11.4)	16.8 (17.4)	0.343	14.2 (14.8)	18.3 (19.1)	0.393	12.3 (11.2)	16.9 (17.9)	0.373
2 years MCID	55.6%	71.4%	0.362	67.9%	68.8%	0.951	75.0%	50.0%	0.113

Bold value indicates statistical significance

Table 9 Patient reported outcomes by readmissions/reoperations

	Mean SRS Scores				Mean ODI scores			
	Baseline	1 year	2 years	2 years MCID%	Baseline	1 year	2 years	2 years MCID%
All	59.9 (21.6)	84.8 (17.3)	87.9 (14.9)	86.4	35.5 (19.6)	18.3 (17.1)	16.6 (15.8)	68.2
No read/reop	59.9 (23.4)	85.9 (16.5)	87.4 (15.9)	83.4	33.4 (19.8)	18. 0 (15.1)	16.9 (16.9)	64.9
Readmitted	60.1 (10.8)	78.5 (19.7)	90.6 (7.4)	100	44.9 (14.6)	20.3 (21.5)	15.5 (14.9)	83.3
Revised	56.6 (9.7)	71 (18.8)	90.9 (7.8)	100	45.6 (15.9)	23.8 (22.6)	13.4 (13.6)	85.7

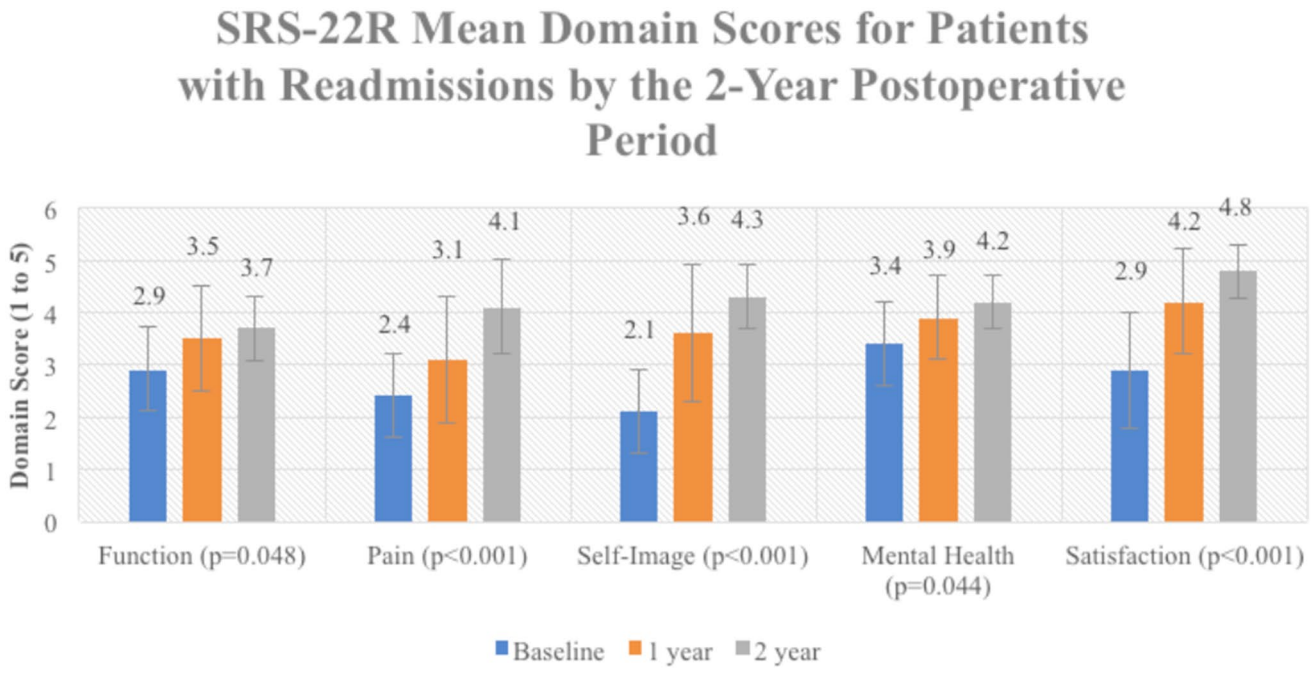

Fig. 1 A comparison of the mean SRS-22R domain scores by follow-up period (preoperative baseline, 1 year, 2 years) for patients who had a readmission

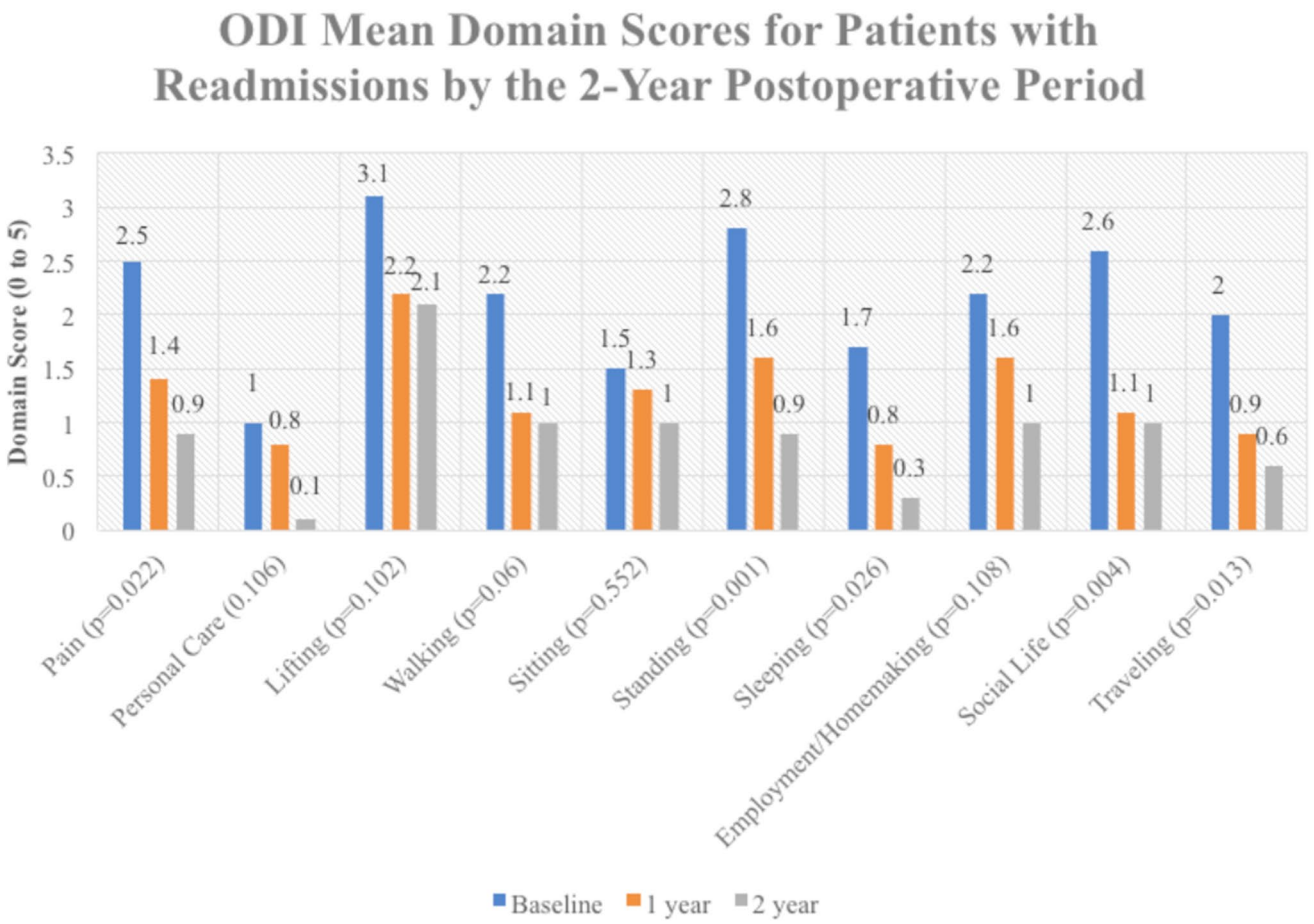

Fig. 2 A comparison of the mean ODI domain scores by follow-up period (preoperative baseline, 1 year, 2 years) for patients who had a readmission

Table 10 Patient reported outcomes by complications

	Reversible	Permanent	*p* value
SRS			
Baseline	59.6 (22.2)	64.7 (14.3)	0.470
1 year	84.8 (17.6)	71 (25.9)	0.102
2 years	89.2 (14.2)	67.7 (21.1)	***0.016***
2 years MCID	85.7%	15.4%	**< 0.001**
ODI			
Baseline	34.8 (20)	43.4 (14)	0.185
1 year	17.8 (17)	27.2 (16)	0.234
2 years	15.2 (15.1)	33.3 (29.0)	0.063
2 years MCID	66.7%	15.4%	***0.001***

the results are somewhat conflicting. In a single-center retrospective study, Riley et al. [35] examined HRQoL in complex ASD patients based on Scoli-RISK-1 (SR-1) criteria with minimum 2-year follow-up. Their ASD population was considerably more complex given that nearly 40% of patients underwent a 3CO and 23.4% of patients suffered a major complication. Nevertheless, significant improvements were observed in all SRS-22r domains, and more than 50% achieved MCID by 2 years postoperative. Similar to our study, the greatest improvements occurred in SRS pain and self-image domains. However, patients with postoperative neurological deficit or a major complication were unlikely to achieve MCID for the SRS function domain. It is possible that patients with permanent complications are less likely to experience substantial improvements in HRQoL. Auerbach et al. [36] studied outcomes in patients who underwent 3COs for ASD and showed that patients with permanent major complications seemed to have lower mean satisfaction rates, but the difference was not statistically different from those with transient complications. By 2 years, patients who experienced major complications were still able to achieve satisfactory clinical outcomes. In contrast, Glassman et al. demonstrated that major complications negatively impact PROs for ASD patients compared to those with only minor or no complications. This study was limited to a 1-year postoperative follow-up, which may not be sufficient time to account for potentially recoverable complications [37]. In

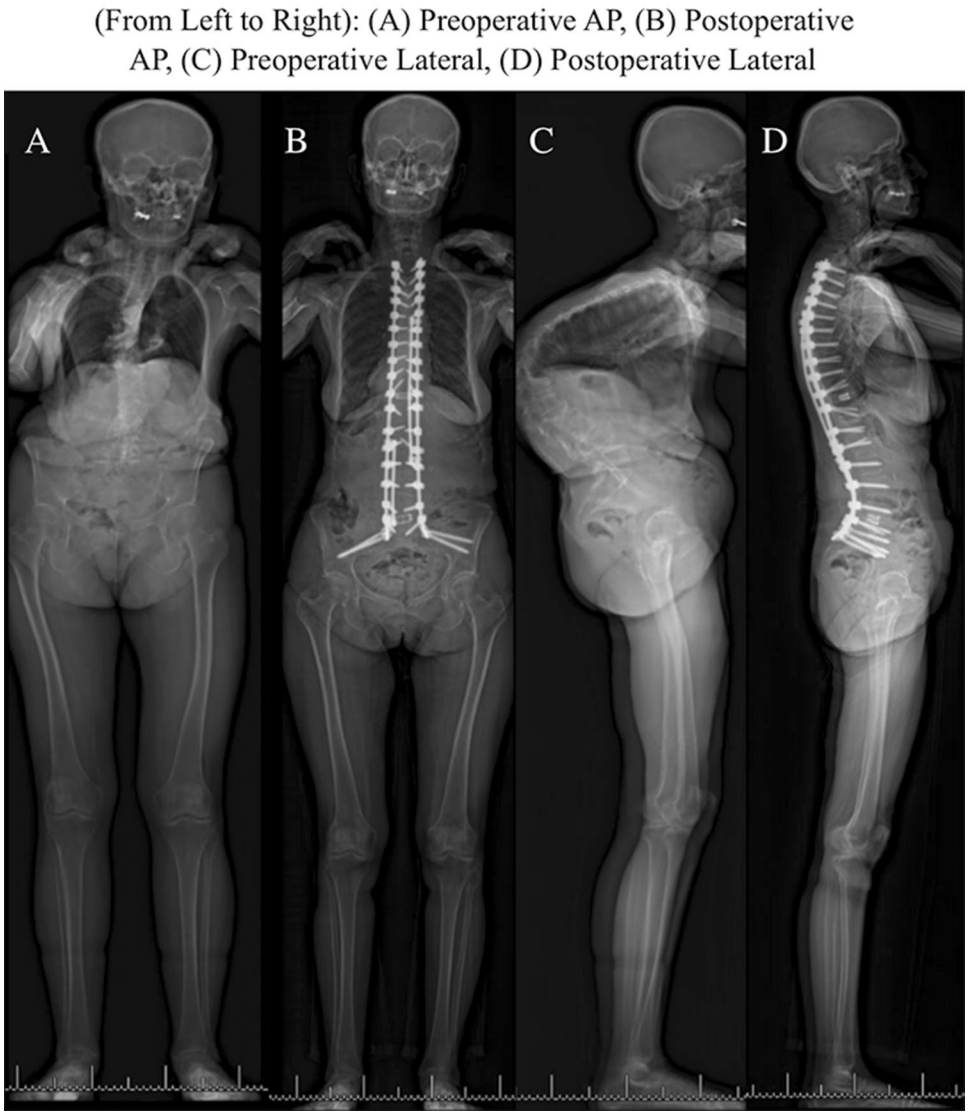

Fig. 3 The preoperative anterior–posterior (**a**) and lateral (**c**) radiographs show patient AB with severe thoracolumbar osteoporotic kyphosis (> 100°). Her surgery involved posterior spinal instrumented fusion from T1 to pelvis, multiple PCOs (8), T11 VCR, TLIF L5-S1 as shown in (**b**) and (**d**)

our study, we found that those with "any inpatient" complication had worse ODI at 1 year, but the differences were not significant at 2 years. Furthermore, the 2-year MCID% was not significantly different between those with and without "any inpatient" complication, "intraoperative" complication, and "inpatient postoperative" complication for either SRS or ODI. These prior studies provide valuable information, but did not examine the impact of revision surgery or readmission on PROs.

In a prospective multicenter study, Passias et al. [34] reviewed the readmission and reoperation data in an ASD population defined by radiographic parameters. They reported a 22.8% readmission rate and 19.5% reoperation rate. Similar to our findings, a major reason for revision surgery was implant failure. HRQoL analysis revealed an overall improvement in the total population but less improvement in those who were readmitted. Undergoing reoperation following readmission did not have any impact on HRQoL. In our analysis, patients who required either a reoperation or readmission achieved significantly better PROs at 2 years compared to 1 year and baseline values. When comparing 2-year PROs for those readmitted versus not, there was no statistical difference for either SRS or ODI.

The fact that readmitted and revised patients were able to recover as well as those without readmission is likely attributed, at least in part, to the high-volume nature of our spine-focused hospital and aggressive attention for any complication requiring readmission and/or reoperation. Fluid communication between the surgeons and their staff, ancillary subspecialty teams, and the patient can lead to prompt and effective management of complications and overall improved patient outcomes.

A number of limitations must be acknowledged for this study. First, although this was a retrospective review, all of the data was prospectively entered into a standardized electronic database on a continual basis and all patients

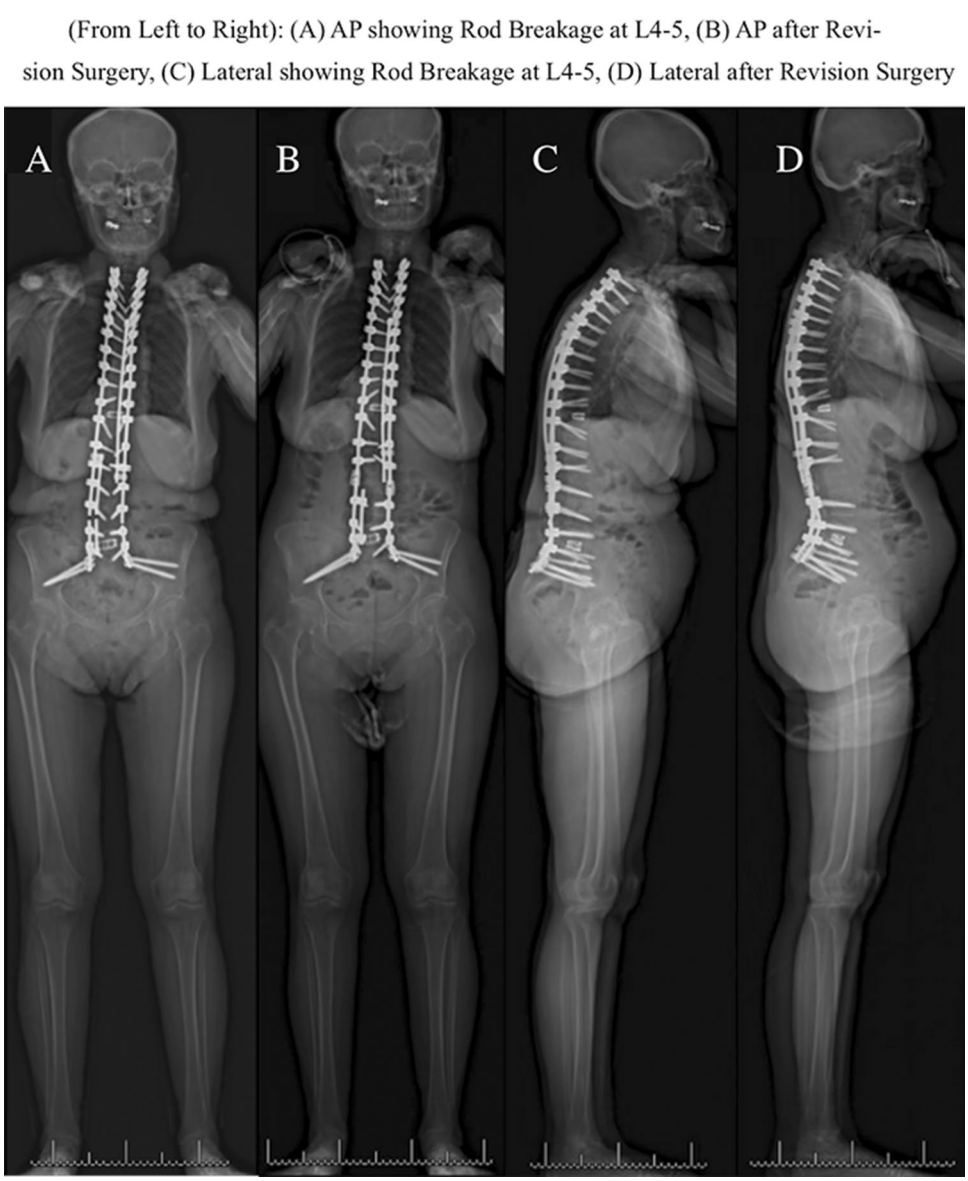

Fig. 4 Patient AB was readmitted for new onset lower back pain and found to have rod fractures at L4-5 (**a**, **c**). She underwent revision instrumentation from L1 to pelvis with repair of the pseudarthrosis at L4-5 (**b**, **d**)

were consecutively enrolled. Unfortunately, nearly 30% of patients were lost to follow-up by 2 years postoperative. Those without follow-up had a similar preoperative comorbidity burden (ASA > 2: 29.1% [with follow-up] vs. 26.4% [without follow-up]; $p = 0.663$) and baseline operative characteristics (TIL: 13.3 [with follow-up] vs. 13.7 [without follow-up]; $p = 0.418$; operative time: 473 min [with follow-up] vs. 461 min [without follow-up]; $p = 0.504$; PSO: 5.7% [with follow-up] vs. 5.6% [without follow-up]; $p = 0.961$; VCR: 8% [with follow-up] vs. 9.7% [without follow-up]; $p = 0.659$; TLIF: 69.1% [with follow-up] vs. 66.7% [without follow-up]; $p = 0.643$). Nevertheless, it is possible with lack of follow-up that we underestimated the true readmission/reoperation rates and overestimated the benefit of surgery based on PRO's. Next, given the single-center nature of our study, our findings may not be generalizable to other institutions who treat ASD patients. Finally, complications including pseudarthrosis and PJK are known to occur beyond the 2-year follow-up period. Studies with extended follow-up periods are needed to understand the full extent of long-term complications.

Conclusion

Our results demonstrate that the vast majority of patients can achieve clinically significant improvement in HRQoL after complex ASD surgery. Major improvements were observed in every domain of the SRS survey and several domains of the ODI survey (pain, standing, sleeping, social life, and traveling). Several predictors were identified for unplanned readmissions which may help surgeons with preoperative risk-stratification. Furthermore, and somewhat surprisingly, our findings suggest that readmissions and revision surgery do not adversely affect PRO's in complex ASD patients by 2 years postoperative. Those who require an unplanned readmission or reoperation can significantly improve their HRQoL by 2-year follow-up compared to preoperative-baseline and 1-year follow-up as well as achieve similar improvements compared to those who did not require a readmission. These findings can provide valuable insight for patients and providers during the shared decision-making process for these complex surgical cases.

Author contributions NL and MC: substantial contributions to the conception and design of the work; the acquisition, analysis, and interpretation of data for the work, drafting the work and revising it critically for important intellectual content, final approval of the version to be published, contributed effort to the study; EL and ZS: substantial contributions to the conception and design of the work; the acquisition, analysis, and interpretation of data for the work, revising the work critically for important intellectual content, final approval of the version to be published, contributed effort to the study; RAL and LGL: substantial contributions to the conception and design of the work, revising the work critically for important intellectual content, final approval of the version to be published, contributed cases or effort to the study.

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Compliance with ethical standards

Conflict of interest LGL reports being a consultant for Medtronic (money donated to charity); receiving royalties from Medtronic and Quality Medical Publishing; receiving reimbursement for airfare and hotels from Broadwater, the Seattle Science Foundation, Stryker Spine, the Spinal Research Foundation, AOSpine, and the Scoliosis Research Society; receiving grant support from the Scoliosis Research Society (money to his institution), EOS Imaging (money to his institution), the Setting Scoliosis Straight Foundation (money to his institution); and receiving grant and fellowship support from AOSpine (money to his institution). Authors RAL/ZMS/EL/NJL/MC report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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