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ORIGINAL ARTICLE

Recovery following adult spinal deformity surgery: the effect of complications and reoperation in 149 patients with 2-year follow-up

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Abstract
Purpose To identify the effect of complications and reoperation on the recovery process following adult spinal deformity (ASD) surgery by examining health-related quality of life (HRQOL) measures over time via an integrated health state analysis (IHS).
Methods A retrospective review of a multicenter, prospective ASD database was conducted. Complication number, type, and need for reoperation (REOP) or not (NOREOP) were recorded. Patients were stratified as having no complication (NOCOMP), any complication (COMP), only minor complications (MINOR) and any major complications (MAJOR). HRQOL measures included Oswestry Disability Index (ODI), Short Form-36 (SF-36), and Scoliosis Research Society-22 (SRS22) at baseline, 6 weeks, 1 and 2 years postoperatively. All HRQOL scores were normalized to each patient's baseline scores and an IHS was then calculated.
Results 149 patients were included. COMP, MINOR, and MAJOR had significantly lower normalized SRS mental scores at 1 and 2 years than NOCOMP ($p < 0.05$). REOP had significantly worse normalized 1 and 2 year mental component score (MCS), SRS mental, and total score than NOCOMP ($p < 0.05$). COMP, MINOR, and MAJOR all had significantly lower SRS mental IHSs than NOCOMP ($p < 0.05$). REOP had significantly lower IHSs for MCS and SRS satisfaction than NOREOP ($p < 0.05$). REOP had a significantly lower MCS and SRS mental IHS than NOCOMP ($p < 0.05$).
Conclusion An IHS analysis suggests there was a significantly protracted mental recovery phase associated with patients that had at least one complication, as well as either

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a minor and major complication. The addition of a reoperation also adversely affected the mental recovery as well as overall satisfaction.

Keywords Adult spinal deformity · Integrated health state · Complications · Reoperation · HRQOL · Area under the curve

Introduction

Complication rates following surgery for adult spinal deformity (ASD) range from 14 to 71 % [1–6] and their effect on health-related quality of life (HRQOL) reported in the literature are mixed [7–11]. While a couple of studies [7, 9] found that complications did not affect clinical outcomes, Glassman and colleagues [10] found that only major, and not minor, complications adversely affected general health status. Cho's [8] study investigating revision surgery in ASD found that patients with post-operative complications had lower HRQOL at final follow-up. It remains unclear how complications and reoperations affect HRQOL outcomes.

Assessing the success of surgical interventions involves comparing pre-operative and post-operative time points [12–17] but are frequently based on averages of predefined groups rather than accounting for individual changes within the time frame studied. Both minimal clinically important difference (MCID) and substantial clinical benefit (SCB) thresholds have been determined to increase the clinical utility of standard HRQOL measures [16, 18, 19]. However, these values only account for pre-operative and post-operative states at discreet time points without addressing the continuum of the post-operative experience.

It is possible that current methods of reporting HRQOL may miss changes within the post-operative period and fluctuations in individual HRQOL, thus perhaps diminishing the health impact of the entire post-operative recovery experience (recovery kinetics). Furthermore, it has yet to be determined whether complications or reoperations affect recovery. To gauge the 2-year post-operative recovery kinetics based on complications and reoperations, a normalization process for the HRQOL scores was used to calculate a novel integrated health state (IHS) over the 2-year post-operative period.

Methods

Patient population

This study is a retrospective review of a prospective multicenter ASD database composed of 11 sites across the United States. All patients were enrolled into an Institutional Review Board-approved protocol by each site. Inclusion criteria for the database were: age ≥18 years and presence of spinal deformity, as defined by one or more of the following: scoliosis Cobb angle ≥20°, sagittal vertical axis (SVA) ≥5 cm, pelvic tilt (PT) ≥25°, and/or thoracic kyphosis (TK) ≥60°. Exclusion criteria included spinal deformity of a neuromuscular etiology and presence of active infection or malignancy. In addition to the criteria above, included patients were required by the integrated health state analysis (described below) to have complete pre-operative, 6 week, 1 year, and 2 year HRQOL data recorded.

Data collection, radiographic assessment, and HRQOL

Demographic and clinical data included patient age, gender, body mass index (BMI), and Charlson Comorbidity Index (CCI) [20]. Surgical data collected included: American Society of Anesthesiologists (ASA) physical status classification, length of hospital stay (LOS), operating room time (OR time), estimated blood loss (EBL), complication number, type, and need for reoperation. Patients were stratified as having no complication (NOCOMP), any complication (COMP), and requiring reoperation (REOP). Staged index surgeries were not counted as reoperations. Patients sustaining at least 1 minor complication with and without major complications were grouped as MAJOR and MINOR, respectively. EBL >4 L was excluded as it is unlikely that this has any significant role in HRQOL outcomes in the absence of apparent associated complications. Reoperation indications included: implant failure, infection, neurologic deficit, cardiopulmonary, vascular, gastrointestinal, operative, renal, wound problems, and radiographic.

Standardized HRQOL measures included the Oswestry Disability Index (ODI), Short Form-36 (SF-36), and Scoliosis Research Society-22 (SRS-22). Two standard summary scores were calculated based on the SF-36, the Physical Component Score (PCS) and the Mental Component Score (MCS). The SRS-22 provides both a total score and multiple subdomains, including activity, pain, appearance, mental, and satisfaction. Minimal clinically important difference (MCID) and substantial clinical benefit (SCB) values have been established for the HRQOL instruments to place HRQOL outcomes in a clinically relevant context [19, 21]. The MCID/SCB values for ODI and PCS used in the present study included: ODI (−15/−18.8), PCS (+5.2/+6.2), and the MCID values for the SRS subdomains included: activity (+0.375), pain (+0.587), appearance (+0.8), and mental (+0.42) [16, 18, 19, 21]. All HRQOL time points were recorded from the index surgery, even for patients undergoing reoperations.

Full-length free-standing lateral spine radiographs (36" cassette) at baseline, 6-weeks, 1-year, and 2-year follow-up

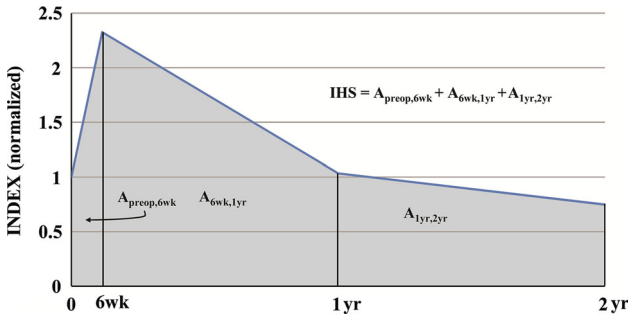

Fig. 1 The integrated health state (IHS) calculation involves the summation of the areas between each time point, calculated as trapezoids. For example, the area of the first trapezoid is represented as the following: $A_{\text{preop,6week}} = \frac{\Delta X}{2}\left(y_{\text{preop}} + y_{\text{6week}}\right)$. The y values represent the given HRQOL value at the respective time point. The change in time was calculated as weeks and then divided by 52 weeks to convert the units back to years and produce reasonably sized IHS values. The actual equation used for each patient was the following: $\text{IHS} = \frac{\frac{6}{2}\left(y_{\text{preop}}+y_{\text{6week}}\right)+\frac{46}{2}\left(y_{\text{6week}}+y_{\text{1year}}\right)+\frac{52}{2}\left(y_{\text{1year}}+y_{\text{2year}}\right)}{52}$

were analyzed at a central location based on standard techniques [22] using validated software [23, 24] (Spineview®, ENSAM, Laboratory of Biomechanics, Paris, France). Radiographic parameters included coronal Cobb angles, TK (T4-T12), lumbar lordosis (LL, L1-S1), C7 SVA, PT, and mismatch between pelvic incidence (PI) and LL (PI-LL). The coronal curves were additionally stratified by the SRS-Schwab adult spinal deformity classification [25].

Statistical analyses and integrated health state

HRQOL measures were analyzed using the standard reported scores and were normalized to each patient's pre-operative value, which allowed for calculation of an integrated health state (IHS) over the 2-year post-operative period. A line connecting all HRQOL values and the area below this line was calculated by summing the areas of three trapezoids (Fig. 1) to yield a single value representing the total IHS across 2-years. For example, the area (A) between the pre-operative and 6-week time points was calculated as the following: $A_{\text{preop,6wk}} = \frac{\Delta X}{2}\left(y_{\text{preop}} + y_{\text{6wk}}\right)$, with ΔX being the time between measuring HRQOL values and the y values being the normalized HRQOL values. ΔX was calculated as weeks but converted to years to produce reasonably sized IHS values. The 2-year IHS equation used for each patient was the following:

$$IHS_{\text{2year}} = \frac{\frac{\text{6weeks}}{2}\left(y_{\text{preop}} + y_{\text{6week}}\right) + \frac{\text{46weeks}}{2}\left(y_{\text{6week}} + y_{\text{1year}}\right) + \frac{\text{52weeks}}{2}\left(y_{\text{1year}} + y_{\text{2year}}\right)}{52\ {}^{\text{weeks}}/_{\text{year}}}$$

IHS means for the study groups were compared. For HRQOL scores in which higher values indicate worse outcomes (ODI), a high IHS value would indicate poor recovery kinetics and vice versa. Conversely, HRQOL in which high scores indicate better outcomes (PCS, MCS, SRS subdomains), a high IHS would indicate good recovery kinetics over 2-years.

Continuous variables were described with the mean and standard deviation. Normality of data was determined using the Shapiro-Wilk test. Comparison of means between the groups initially included an analysis of variance (ANVOA) or Kruskal-Wallis test were appropriate, which was followed by pairwise comparisons using Tukey's Honest Significant Difference test to control for type I error or Wilcoxon summed ranked tests where appropriate. Frequency analysis was used for categorical variables. The rates of meeting MCID or SCB were compared using a χ^2 analysis. All statistical analyses were conducted using JMP (v7.0, SAS Institute, Inc., Cary, NC) with significance defined by $p < 0.05$.

Results

Patient population

286 patients were eligible and 235 (82.2 %) had complete 2-year clinical and radiographic follow-up. Of those, 149 (63.4 %) had complete pre-operative, 6 week, 1-, and 2-year HRQOL. Demographic variables are shown in Table 1 and were statistically similar between groups ($p > 0.05$). 65 patients were without complications (NOCOMP, Table 2). 84 patients sustained at least 1 complication (56.4 %, COMP) and of these, 45 had at least 1 minor complication without any major complications (30.2 %, MINOR), 39 sustained at least 1 major complication (26.2 %, MAJOR), 28 of which required a reoperation (18.8 %, REOP). 56 did not undergo any reoperation (NOREOP, Table 2). No significant differences were noted in the distribution of SRS-Schwab coronal class types between groups ($p > 0.05$, Table 1) except for the REOP group which had a significantly higher percentage of patients with Type N and L compared to NOREOP which had significantly higher percentages of Types T and D ($p < 0.05$, Table 1). Of the MAJOR group, Table 3 lists indications for the REOP group.

Table 1 Demographic and baseline SRS-Schwab coronal classification for the comparison groups

	COMP	MINOR	MAJOR	NOCOMP	REOP	NOREOP
Number	84	45	39	65	28	56
Age	55.8 ± 15.1	52.6 ± 15.3	59.6 ± 14.1	56.9 ± 16.2	59 ± 15.8	54.4 ± 14.5
Female:male	75:9	42:3	33:6	49:16	22:6	51:4
BMI	27.3 ± 6.3	26.3 ± 5.2	28.5 ± 7.3	26.1 ± 6.3	27.8 ± 6.3	27.3 ± 6.4
ASA	1.6 ± 1.7	1.6 ± 2	1.5 ± 1.4	1.2 ± 1.3	1.2 ± 1.5	1.8 ± 1.9
CCI	2.3 ± 0.7	2.3 ± 0.7	2.3 ± 0.6	2.1 ± 0.6	2.3 ± 0.5	2.3 ± 0.7
LOS	7.8 ± 3.5	7.6 ± 3	8 ± 4.1	7.9 ± 4	8.1 ± 4.1	7.8 ± 3.1
OR time	396.2 ± 144.3	392.5 ± 130.2	400.5 ± 160.8	381.9 ± 127.8	394.7 ± 149.4	406.8 ± 134
EBL	1,591.5 ± 1,182.5	1,574.4 ± 1,090.7	1,612.2 ± 1,300.5	2,354.7 ± 2,222.7	2,137.1 ± 2,613.7	1,630 ± 1,117
Preop SRS-Schwab coronal curve						
Type N	20 (24.1 %)	7 (15.6 %)	13 (34.2 %)	21 (32.8 %)	10 (35.7 %)	10 (18.2 %)
Type T	27 (32.5 %)	17 (37.8 %)	10 (26.3 %)	23 (35.9 %)	5 (17.9 %)	22 (40 %)
Type L	15 (18.1 %)	6 (13.3 %)	9 (23.7 %)	7 (10.9 %)	8 (28.6 %)	7 (12.7 %)
Type D	21 (25.3 %)	15 (33.3 %)	6 (15.8 %)	13 (20.3 %)	5 (17.9 %)	16 (29.1 %)

NOCOMP patients without any complication over 2 years, *COMP* patients that sustained at least one complication, *REOP* patients that underwent a revision for the index surgery or a reoperation for another complication, *NOREOP* patients that had at least one complication but did not require a revision or reoperation, *MINOR* patients that sustained only a minor complication, *MAJOR* patients that sustained at least one major complication [they may also have minor complication(s)], *BMI* Body Mass Index, *ASA* American Society of Anesthesiologists physical status classification, *CCI* Charlson Comorbidity Index, *LOS* length of hospital stay, *OR time* operating room time, *EBL* estimated blood loss, *Type N* patients with no coronal curve greater than 30° (i.e. no major coronal deformity), *Type T* patients with a thoracic major curve of greater than 30° (apical level of T9 or higher), *Type L* patients with a lumbar or thoracolumbar major curve of greater than 30° (apical level of T10 or lower), and *type D* patients with a double major curve, with each curve greater than 30°

Table 2 Number and percentage of complications for each group

	COMP	MINOR	MAJOR	REOP	NOREOP
Total no of patients	84 (100 %)	45 (100 %)	39 (100 %)	28 (100 %)	56 (100 %)
No. of patients with minimum 1 intra-operative	23 (27.4 %)	8 (17.8 %)	15 (38.5 %)	7 (25 %)	16 (28.6 %)
No. of patients with minimum 1 peri-operative	55 (65.5 %)	33 (73.3 %)	22 (56.4 %)	18 (64.3 %)	37 (66.1 %)
No. of patients with minimum 1 post-operative	46 (54.8 %)	18 (40 %)	28 (71.8 %)	25 (89.3 %)	21 (37.5 %)
No. of patients with minimum 1 revision	23 (27.4 %)	0 (0 %)	22 (56.4 %)	23 (82.1 %)	0 (0 %)
No. of patients with minimum 1 reoperations	26 (31 %)	0 (0 %)	26 (66.7 %)	26 (92.9 %)	0 (0 %)
Minor	45 (53.6 %)	45 (100 %)	0 (0 %)	0 (0 %)	44 (78.6 %)
Major	39 (46.4 %)	0 (0 %)	39 (100 %)	28 (100 %)	12 (21.4 %)
Number of complications					
1	39 (46.4 %)	25 (55.6 %)	14 (35.9 %)	9 (32.1 %)	30 (53.6 %)
2	22 (26.2 %)	14 (31.1 %)	8 (20.5 %)	5 (17.9 %)	17 (30.4 %)
3	11 (13.1 %)	2 (4.4 %)	9 (23.1 %)	8 (28.6 %)	3 (5.4 %)
4	7 (8.3 %)	3 (6.7 %)	4 (10.3 %)	3 (10.7 %)	4 (7.1 %)
5 or greater	5 (6 %)	1 (2.2 %)	4 (10.3 %)	3 (10.7 %)	2 (3.6 %)

The percentage is out of the total patients in each age group

COMP patients that sustained at least one complication, *REOP* patients that underwent a revision for the index surgery or a reoperation for another complication, *NOREOP* patients that had at least one complication but did not require a revision or reoperation, *MINOR* patients that sustained only a minor complication, *MAJOR* patients that sustained at least one major complication [they may also have minor complication(s)]

Standard HRQOL scores

There were no significant differences in mean HRQOL scores at any time point between NOCOMP and both COMP and MINOR, respectively ($p > 0.05$, Table 4). There were no differences in mean baseline HRQOL scores between MINOR and MAJOR ($p > 0.05$) except that MAJOR had significantly higher ODI ($p < 0.05$). MAJOR

Table 3 The indications for reoperations for the REOP group

Parameter	No.
Total no.of patients	28
Total no. of reoperations	34
Reoperation types	# (% of 34)
Implant failure	8 (23.5 %)
Infection	3 (8.8 %)
Neurologic	2 (5.9 %)
Cardiopulmonary	0 (0 %)
Vascular	0 (0 %)
Gastrointestinal	0 (0 %)
Operative	3 (8.8 %)
Renal	0 (0 %)
Wound problems	1 (2.9 %)
Radiographic	17 (50 %)

had worse 1- and 2-year ODI, PCS, SRS activity, appearance and total compared to NOCOMP ($p < 0.05$, Table 4). In addition, MAJOR had worse 6 week, 1- and 2-year SRS activity, appearance, satisfaction, and total, as well as worse 1- and 2-year ODI and PCS than MINOR ($p < 0.05$, Table 4). REOP and NOREOP groups had statistically similar baseline standard HRQOL scores ($p > 0.05$), but REOP had significantly worse 6 week SRS activity, appearance and total, as well as both 1- and 2-year ODI, PCS, SRS activity, appearance, pain, total compared to NOREOP ($p < 0.05$, Table 4). REOP had worse standard HRQOL scores than NOCOMP for both 1- and 2-year ODI, PCS, SRS appearance, pain, and total ($p < 0.05$, Table 4).

Each group significantly improved in all mean standard HRQOL scores at 2 years compared to pre-operative ($p < 0.05$, Table 4; Figs. 2, 3) except for SRS mental and MCS for COMP, MINOR, MAJOR, REOP, and NOREOP ($p < 0.05$, Table 4). Although REOP improved in all HRQOL scores at 2 years, only SRS pain, appearance, satisfaction, and total score reached significance ($p < 0.05$).

Normalized HRQOL scores

COMP, MINOR, and MAJOR all had significantly lower normalized SRS mental at both 1 and 2 years post-operative as well as lower normalized 1 year MCS and 2 year SRS total score than NOCOMP, ($p < 0.05$ for all, Table 5; Figs. 2, 3) except for MCS for NOCOMP versus MINOR. In addition, MAJOR had worse normalized 1 year SRS activity and both 1 and 2 year SRS total than MINOR ($p < 0.05$). No other significant differences were noted ($p > 0.05$ for all). There were no significant differences between REOP and NOREOP for any of the normalized HRQOL at any time point ($p > 0.05$, Table 5). REOP had significantly worse normalized 1 and 2 year MCS, SRS mental and total as well as 1 year PCS and 2 year SRS activity and mental than NOCOMP ($p < 0.05$, Table 5).

Integrated health state (IHS)

COMP, MINOR, and MAJOR all had significantly lower IHS for SRS mental than NOCOMP ($p < 0.05$, Table 6; Fig. 3). REOP had significantly lower IHS values for MCS and SRS satisfaction ($p < 0.05$, Table 6). REOP had a significantly lower MCS and SRS mental IHS compared to NOCOMP ($p < 0.05$). No other IHS values were statistically different between groups ($p > 0.05$).

MCID and SCB

COMP, MINOR, MAJOR, and REOP were all significantly less likely to reach MCID at 2 years for SRS mental than NOCOMP ($p < 0.05$, Table 7). COMP and REOP were also significantly less likely to reach 2 year MCID for SRS mental than NOREOP ($p < 0.05$). Furthermore, COMP was significantly less likely to reach MCID at 2 years for PCS than NOCOMP ($p < 0.05$). All other rates of meeting MCID and SCB were statistically similar between groups ($p > 0.05$, Table 7).

Discussion

Based on a novel method using individual normalized HRQOL scores and integrating these scores over time to produce an integrated health state (IHS), we determined a significant protracted mental recovery phase associated with patients that had at least one complication, a minor or major complication. For patients that sustained any complication, an additional reoperation adversely affected the metal component and overall satisfaction of recovery.

The normalized HRQOL analysis provides insight into IHS differences. Significant differences in the SRS mental subdomain score existed only between NOCOMP and the other complication groups at the 1 and 2 year time points where the NOCOMP patients had a large improvement in SRS mental score. The fact that COMP, MINOR, MAJOR, and REOP were significantly less likely to reach MCID at 2 years for SRS mental than NOCOMP suggests that complications and reoperation also affect the final outcomes of SRS mental. In addition to differences in recovery kinetics, 2-year change in SRS mental score also differed as evidenced by the MCID values.

To our knowledge, no studies have addressed the effect of complications on recovery kinetics. Few studies have attempted to characterize the effect of complications on clinical outcomes but used different HRQOL values. Albert et al. [7] found that complications did not affect outcomes

Table 4 Complete standard HRQOL values for all comparison groups and time points

HRQOL standard	ODI	PCS	MCS	SRS activity	SRS pain	SRS appearance	SRS mental	SRS satisfaction	SRS total
Preop									
COMP ($n = 84$)	40.3 ± 19	33.5 ± 9.9	47.3 ± 13.4	3.1 ± 1	2.5 ± 0.8	2.5 ± 0.7	3.6 ± 0.9	2.7 ± 1	2.9 ± 0.7
MINOR ($n = 45$)	36.3 ± 20.1	35.8 ± 10.3	47.2 ± 14.2	3.3 ± 0.9	2.6 ± 0.8	2.6 ± 0.7	3.6 ± 0.9	2.7 ± 1	3 ± 0.7
MAJOR ($n = 39$)	44.8 ± 16.8	31.1 ± 8.9	47.4 ± 12.5	2.9 ± 1	2.3 ± 0.8	2.4 ± 0.7	3.6 ± 1	2.7 ± 1.1	2.8 ± 0.7
NOCOMP ($n = 65$)	40.7 ± 19.8	32.8 ± 11.3	43.9 ± 13.6	3 ± 1	2.7 ± 0.9	2.5 ± 0.8	3.4 ± 0.9	2.9 ± 1	2.9 ± 0.7
REOP ($n = 28$)	44 ± 16.5	32.3 ± 9.5	47.4 ± 11.4	2.9 ± 1	2.2 ± 0.8	2.5 ± 0.7	3.6 ± 1	2.9 ± 1.1	2.8 ± 0.7
NOREOP ($n = 56$)	37.9 ± 19.2	34.3 ± 10.1	47.1 ± 14.1	3.2 ± 0.9	2.6 ± 0.8	2.5 ± 0.7	3.6 ± 0.9	2.6 ± 1.1	2.9 ± 0.7
6 weeks									
COMP ($n = 84$)	45.1 ± 19.9	30.8 ± 8.3	44.5 ± 14.3	2.6 ± 0.8	2.4 ± 0.8	3.5 ± 0.9	3.6 ± 0.9	4.1 ± 0.9	3.1 ± 0.6
MINOR ($n = 45$)	41.6 ± 18.9	31.7 ± 8.4	44.9 ± 15	2.7 ± 0.7	2.5 ± 0.9	3.7 ± 0.9	3.6 ± 1	4.3 ± 0.7	3.2 ± 0.7
MAJOR ($n = 39$)	49.1 ± 20.4	29.6 ± 8.1	44.1 ± 13.5	2.4 ± 0.8	2.3 ± 0.8	3.2 ± 0.8	3.5 ± 0.8	3.9 ± 1	3 ± 0.6
NOCOMP ($n = 65$)	46.5 ± 16.9	29.6 ± 9.9	48.2 ± 12.7	2.6 ± 0.7	2.4 ± 0.8	3.5 ± 0.9	3.6 ± 0.8	4.2 ± 1	3.1 ± 0.6
REOP ($n = 28$)	50.1 ± 20.2	29.1 ± 8.6	44.1 ± 14.3	2.3 ± 0.6	2.1 ± 0.7	3.2 ± 0.8	3.7 ± 0.7	3.9 ± 0.9	2.9 ± 0.5
NOREOP ($n = 56$)	43.1 ± 18.9	31.5 ± 8.2	45 ± 14.3	2.7 ± 0.8	2.5 ± 0.9	3.6 ± 0.9	3.5 ± 0.9	4.2 ± 0.8	3.2 ± 0.6
1 year									
COMP ($n = 84$)	29.9 ± 20.7	39.9 ± 11.3	48.6 ± 14.6	3.5 ± 1	3.3 ± 1.1	3.6 ± 0.9	3.8 ± 1	4.2 ± 1	3.6 ± 0.8
MINOR ($n = 45$)	23.9 ± 18.4	44 ± 10	50.9 ± 13.1	3.8 ± 0.9	3.6 ± 1	3.8 ± 0.9	3.9 ± 0.9	4.4 ± 0.9	3.8 ± 0.8
MAJOR ($n = 39$)	36.5 ± 21.4	35.3 ± 11	46.1 ± 15.9	3.1 ± 1	3 ± 1.1	3.3 ± 0.9	3.7 ± 1.1	3.9 ± 1.1	3.3 ± 0.9
NOCOMP ($n = 65$)	25.4 ± 17.6	42.2 ± 9.7	52.6 ± 11.5	3.5 ± 0.9	3.4 ± 1	3.8 ± 0.8	4 ± 0.9	4.4 ± 0.8	3.7 ± 0.7
REOP ($n = 28$)	36.7 ± 22.1	35.5 ± 11.3	46 ± 15.9	3.1 ± 1	2.9 ± 1	3.3 ± 1	3.7 ± 1.1	3.9 ± 1.1	3.3 ± 0.9
NOREOP ($n = 56$)	25.6 ± 18.5	42.3 ± 10.5	50.3 ± 13.6	3.7 ± 1	3.5 ± 1	3.8 ± 0.9	3.9 ± 1	4.3 ± 0.9	3.8 ± 0.8
2 years									
COMP ($n = 84$)	26.8 ± 21.3	40.5 ± 11.6	49.4 ± 13.2	3.5 ± 1	3.4 ± 1.1	3.6 ± 0.9	3.8 ± 1	4.2 ± 1	3.6 ± 0.8
MINOR ($n = 45$)	21.9 ± 21.3	43.5 ± 11.2	50.2 ± 13.1	3.8 ± 1	3.6 ± 1.1	3.8 ± 0.9	3.9 ± 0.9	4.2 ± 0.8	3.8 ± 0.8
MAJOR (n = 39)	32.6 ± 20.1	36.8 ± 11.2	48.4 ± 13.5	3.3 ± 1	3.2 ± 1	3.3 ± 0.9	3.7 ± 1	4.1 ± 1.1	3.4 ± 0.8
NOCOMP ($n = 65$)	23.6 ± 18.4	41.9 ± 11.1	52 ± 12.3	3.7 ± 0.9	3.6 ± 1	3.8 ± 0.9	4 ± 0.8	4.4 ± 0.8	3.9 ± 0.8
REOP ($n = 28$)	34.6 ± 21.8	35.2 ± 12.1	47.3 ± 14.2	3.1 ± 1	3 ± 1	3.1 ± 0.9	3.6 ± 1	4 ± 1.2	3.3 ± 0.8
NOREOP ($n = 56$)	23.1 ± 20.3	42.5 ± 11.2	50.3 ± 12.6	3.7 ± 1	3.6 ± 1.1	3.8 ± 0.9	3.9 ± 0.9	4.2 ± 0.8	3.8 ± 0.8

Values are presented as the mean ± 1 standard deviation

NOCOMP patients without any complication over 2 years, *COMP* patients that sustained at least 1 complication, *REOP* patients that underwent a revision for the index surgery or a reoperation for another complication, *NOREOP* patients that had at least one complication but did not require a revision or reoperation, *MINOR* patients that sustained only a minor complication, *MAJOR* patients that sustained at least 1 major complication [they may also have minor complication(s)], *ODI* Oswestry Disability Index, *PCS* Physical Component Score from the Medical Outcomes Short Form 36 questionnaire, *MCS* Mental Component Score from the Medical Outcomes Short Form 36 questionnaire, and the Scoliosis Research Society (SRS) 22 questionnaire

measured by the Medical Outcomes Short Form 36 questionnaire but did not report complication rate. Enami et al. [9] found that peri-operative complications resulted in lower satisfaction, but long-term complications had no effect when investigating 3 different surgical techniques. Only patients with pseudarthrosis or peri-operative complication had lower SRS satisfaction scores [9]. Our results were similar with MAJOR having worse satisfaction at 1 and 2 years than NOCOMP, not accounting for the recovery experience which were all similar based on satisfaction scores. Normalized 2-year satisfaction values were similar between complication groups implying that all groups had the same improvement in satisfaction when accounting for baseline values.

Glassman et al. [10] was the first study to directly investigate complications and HRQOL and found that major complications adversely affected only the general health subscale of the Medical Outcomes Short Form 36 survey. Similarly, our analysis revealed no differences in PCS and MCS IHSs between complication groups.

Cho and colleagues [8] showed that patients in which complications occurred between 6 weeks and 6.5 years post-operative had worse outcomes in all SRS subdomains and ODI than those with peri-operative or no

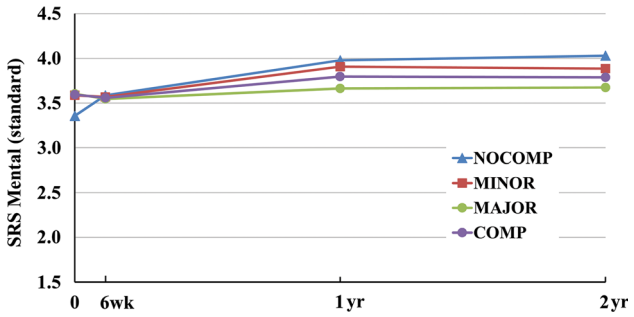

Fig. 2 Mean Standard Scoliosis Research Society (SRS) mental scores across 2 years. *NOCOMP* patients without any complication over 2 years, *COMP* patients that sustained at least one complication, *MINOR* patients that sustained only a minor complication, *MAJOR* patients that sustained at least one major complication [they may also have minor complication(s)]

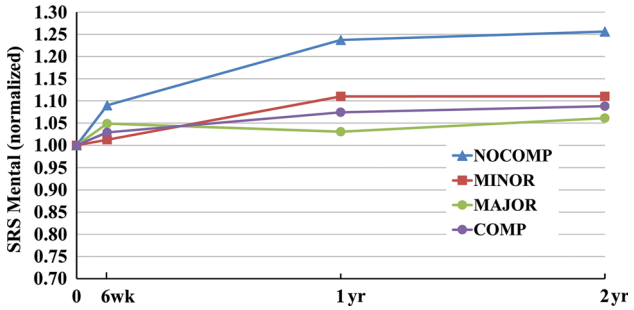

Fig. 3 Mean normalized Scoliosis Research Society (SRS) mental score across 2 years. *NOCOMP* patients without any complication over 2 years, *COMP* patients that sustained at least one complication, *MINOR* patients that sustained only a minor complication, *MAJOR* patients that sustained at least one major complication [they may also have minor complication(s)]

complications [8]. It appears that the closer the complication occurs to when HRQOL is reported, the more likely the complication has an effect on HRQOL. Our analysis allows for characterization of the entire recovery process thus reducing time as a confounder for static time points.

The effect of reoperation on HRQOL in ASD surgery remains unclear. Scheer and colleagues [11] reported an overall reoperation rate of 17 % in a large ASD database and determined that reoperation within 1 year from index surgery adversely affected HRQOL at 1 year [11]. Both reoperation and non-reoperation patients had similar baseline HRQOL but reoperation patients had worse leg pain, ODI, and SRS activity, appearance, pain, and total score [11]. Similarly, this study showed that the REOP group had significantly worse 6 week SRS activity, appearance and total scores, as well as both 1- and 2-year ODI, PCS, SRS activity, appearance, pain, total scores than the NOREOP. Both these studies suggest that clinical outcomes are adversely affected by reoperation. However, static time point analysis accounts for neither individual variation in scores nor changes during the studied time frame. Based on this novel IHS analysis, REOP had significantly lower MCS and SRS satisfaction than NOREOP across 2 years suggesting that reoperation has a significant mental effect on patients.

The multi-center design and multiple time points strengthen this study and allow for better generalizability of results. The lack of consideration for the timing of the complications with respect to the recorded HRQOL time point are limitations since complications close to the

Table 5 Complete normalized HRQOL values for all comparison groups and time points

HRQOL normalized	ODI	PCS	MCS	SRS activity	SRS pain	SRS appearance	SRS mental	SRS satisfaction	SRS total
Preop									
COMP ($n = 84$)	1	1	1	1	1	1	1	1	1
MINOR ($n = 45$)	1	1	1	1	1	1	1	1	1
MAJOR ($n = 39$)	1	1	1	1	1	1	1	1	1
NOCOMP ($n = 65$)	1	1	1	1	1	1	1	1	1
REOP ($n = 28$)	1	1	1	1	1	1	1	1	1
NOREOP ($n = 56$)	1	1	1	1	1	1	1	1	1
6 weeks									
COMP ($n = 84$)	1.4 ± 1.2	1 ± 0.4	1.1 ± 0.5	0.9 ± 0.3	1.1 ± 0.5	1.5 ± 0.7	1 ± 0.2	1.9 ± 1.1	1.1 ± 0.3
MINOR ($n = 45$)	1.6 ± 1.5	1 ± 0.4	1.1 ± 0.5	0.9 ± 0.3	1.1 ± 0.5	1.6 ± 0.7	1 ± 0.2	2 ± 1.1	1.2 ± 0.4
MAJOR ($n = 39$)	1.2 ± 0.7	1 ± 0.4	1 ± 0.4	0.9 ± 0.3	1.1 ± 0.5	1.5 ± 0.6	1 ± 0.3	1.8 ± 1.1	1.1 ± 0.3
NOCOMP ($n = 65$)	1.7 ± 1.8	1 ± 0.4	1.1 ± 0.3	0.9 ± 0.4	1 ± 0.4	1.5 ± 0.6	1.1 ± 0.2	1.7 ± 1	1.1 ± 0.3
REOP ($n = 28$)	1.3 ± 0.8	1 ± 0.4	1 ± 0.3	0.9 ± 0.4	1.1 ± 0.5	1.4 ± 0.6	1.1 ± 0.3	1.7 ± 1.1	1.1 ± 0.3
NOREOP ($n = 56$)	1.5 ± 1.4	1 ± 0.4	1.1 ± 0.5	0.9 ± 0.3	1.1 ± 0.5	1.6 ± 0.7	1 ± 0.2	2 ± 1.2	1.2 ± 0.3

Table 5 continued

HRQOL normalized	ODI	PCS	MCS	SRS activity	SRS pain	SRS appearance	SRS mental	SRS satisfaction	SRS total
1 year									
COMP ($n = 84$)	0.8 ± 0.6	1.2 ± 0.4	1.1 ± 0.5	1.2 ± 0.3	1.4 ± 0.5	1.5 ± 0.6	1.1 ± 0.2	1.9 ± 1.1	1.3 ± 0.3
MINOR ($n = 45$)	0.8 ± 0.7	1.3 ± 0.4	1.2 ± 0.6	1.2 ± 0.3	1.5 ± 0.6	1.6 ± 0.7	1.1 ± 0.3	1.9 ± 1.1	1.3 ± 0.3
MAJOR ($n = 39$)	0.8 ± 0.6	1.2 ± 0.4	1 ± 0.3	1.1 ± 0.3	1.4 ± 0.4	1.4 ± 0.5	1 ± 0.2	1.8 ± 1.2	1.2 ± 0.2
NOCOMP ($n = 65$)	0.7 ± 0.6	1.4 ± 0.6	1.3 ± 0.5	1.3 ± 0.4	1.4 ± 0.6	1.7 ± 0.7	1.2 ± 0.3	1.8 ± 0.9	1.4 ± 0.4
REOP ($n = 28$)	0.9 ± 0.6	1.1 ± 0.5	1 ± 0.2	1.1 ± 0.4	1.4 ± 0.4	1.4 ± 0.4	1 ± 0.2	1.6 ± 0.9	1.2 ± 0.2
NOREOP ($n = 56$)	0.8 ± 0.6	1.3 ± 0.4	1.2 ± 0.6	1.2 ± 0.3	1.4 ± 0.5	1.6 ± 0.6	1.1 ± 0.2	2 ± 1.2	1.3 ± 0.3
2 years									
COMP ($n = 84$)	0.7 ± 0.6	1.3 ± 0.4	1.1 ± 0.4	1.2 ± 0.3	1.5 ± 0.6	1.5 ± 0.6	1.1 ± 0.3	1.9 ± 1.1	1.3 ± 0.3
MINOR ($n = 45$)	0.6 ± 0.6	1.3 ± 0.4	1.2 ± 0.5	1.2 ± 0.4	1.5 ± 0.7	1.6 ± 0.7	1.1 ± 0.3	1.9 ± 1.1	1.3 ± 0.4
MAJOR ($n = 39$)	0.7 ± 0.6	1.2 ± 0.4	1.1 ± 0.3	1.2 ± 0.3	1.5 ± 0.5	1.5 ± 0.5	1.1 ± 0.2	1.8 ± 1.2	1.3 ± 0.3
NOCOMP ($n = 65$)	0.6 ± 0.5	1.4 ± 0.6	1.3 ± 0.6	1.3 ± 0.4	1.5 ± 0.6	1.7 ± 0.7	1.3 ± 0.4	1.8 ± 1	1.4 ± 0.4
REOP ($n = 28$)	0.8 ± 0.6	1.1 ± 0.3	1 ± 0.3	1.1 ± 0.3	1.5 ± 0.5	1.3 ± 0.5	1 ± 0.2	1.7 ± 1.1	1.2 ± 0.2
NOREOP ($n = 56$)	0.6 ± 0.5	1.3 ± 0.4	1.2 ± 0.5	1.2 ± 0.4	1.5 ± 0.7	1.6 ± 0.7	1.1 ± 0.3	2 ± 1.2	1.3 ± 0.4

Values are presented as the mean ± 1 standard deviation

NOCOMP patients without any complication over 2 years, *COMP* patients that sustained at least one complication, *REOP* patients that underwent a revision for the index surgery or a reoperation for another complication, *NOREOP* patients that had at least one complication but did not require a revision or reoperation, *MINOR* patients that sustained only a minor complication, *MAJOR* patients that sustained at least 1 major complication [they may also have minor complication(s)], *ODI* Oswestry Disability Index, *PCS* Physical Component Score from the Medical Outcomes Short Form 36 questionnaire, *MCS* Mental Component Score from the Medical Outcomes Short Form 36 questionnaire, and the Scoliosis Research Society (SRS) 22 questionnaire

Table 6 Complete integrated health state (IHS) values for all comparison groups across 2 years

2 year IHS	NOCOMP ($n = 65$)	MINOR ($n = 45$)	MAJOR ($n = 39$)	COMP ($n = 84$)	REOP ($n = 28$)	NOREOP ($n = 56$)
ODI	2 ± 1.5	2 ± 1.5	1.9 ± 1	1.9 ± 1.3	2 ± 1	1.9 ± 1.4
PCS	2.5 ± 0.9	2.5 ± 0.8	2.3 ± 0.7	2.4 ± 0.7	2.2 ± 0.7	2.5 ± 0.8
MCS	2.4 ± 0.7	2.4 ± 1.1	2.1 ± 0.5	2.2 ± 0.9	2 ± 0.4	2.4 ± 1
SRS activity	2.4 ± 0.8	2.3 ± 0.5	2.2 ± 0.5	2.2 ± 0.5	2.2 ± 0.6	2.3 ± 0.5
SRS pain	2.7 ± 1	2.7 ± 1.1	2.6 ± 0.8	2.7 ± 0.9	2.7 ± 0.8	2.7 ± 1
SRS appearance	3.2 ± 1.2	3.2 ± 1.3	2.9 ± 0.9	3.1 ± 1.1	2.8 ± 0.9	3.2 ± 1.2
SRS mental	2.4 ± 0.5	2.2 ± 0.4	2.1 ± 0.4	2.1 ± 0.4	2.1 ± 0.4	2.2 ± 0.4
SRS satisfaction	3.5 ± 1.8	3.8 ± 2.1	3.6 ± 2.2	3.7 ± 2.1	2.8 ± 1	4.1 ± 2.3
SRS total	2.6 ± 0.6	2.6 ± 0.6	2.4 ± 0.4	2.5 ± 0.5	2.3 ± 0.4	2.6 ± 0.6

Values are presented as the mean ± 1 standard deviation

NOCOMP patients without any complication over 2 years, *COMP* patients that sustained at least 1 complication, *REOP* patients that underwent a revision for the index surgery or a reoperation for another complication, *NOREOP* patients that had at least one complication but did not require a revision or reoperation, *MINOR* patients that sustained only a minor complication, *MAJOR* patients that sustained at least 1 major complication [they may also have minor complication(s)], *ODI* Oswestry Disability Index, *PCS* Physical Component Score from the Medical Outcomes Short Form 36 questionnaire, *MCS* Mental Component Score from the Medical Outcomes Short Form 36 questionnaire, and the Scoliosis Research Society (SRS) 22 questionnaire

recorded HRQOL may affect the values recorded. The MCID/SCB values used in this study were taken from studies in which outcomes were determined from degenerative lumbar arthrodesis patients and have not been validated with deformity patients, thus limiting the generalizability of these MCID/SCB values.

The HRQOL normalization process using baseline HRQOL scores for each patient has inherent limitations since this method starts all patients at a value of 1 (all HRQOL divided by the baseline value) making it appear that all the patients start equally. However, we are aware that there is significant heterogeneity to baseline values.

Table 7 The number and percentage of patients meeting minimal clinically important difference (MCID) and substantial clinical benefit (SCB)

	COMP	MINOR	MAJOR	NOCOMP	REOP	NOREOP
ODI MCID	36 (42.9 %)	19 (42.2 %)	17 (43.6 %)	34 (54.8 %)	12 (41.4 %)	24 (43.6 %)
PCS MCID	35 (48.6 %)	19 (48.7 %)	16 (48.5 %)	35 (62.5 %)	11 (45.8 %)	24 (50 %)
SRS activity MCID	50 (60.2 %)	27 (60 %)	23 (60.5 %)	45 (71.4 %)	16 (55.2 %)	34 (63 %)
SRS pain MCID	57 (68.7 %)	30 (66.7 %)	27 (71.1 %)	43 (68.3 %)	21 (72.4 %)	36 (66.7 %)
SRS appearance MCID	58 (70.7 %)	33 (73.3 %)	25 (67.6 %)	47 (74.6 %)	18 (64.3 %)	40 (74.1 %)
SRS Mental MCID	24 (46.2 %)	16 (35.6 %)	8 (21.6 %)	36 (57.1 %)	4 (14.3 %)	20 (37 %)
ODI SCB	29 (34.5 %)	17 (37.8 %)	12 (30.8 %)	30 (48.4 %)	8 (27.6 %)	21 (38.2 %)
PCS SCB	31 (43.1 %)	18 (46.2 %)	13 (39.4 %)	35 (62.5 %)	8 (33.3 %)	23 (47.9 %)

NOCOMP patients without any complication over 2 years, *COMP* patients that sustained at least 1 complication, *REOP* patients that underwent a revision for the index surgery or a reoperation for another complication, *NOREOP* patients that had at least one complication but did not require a revision or reoperation, *MINOR* patients that sustained only a minor complication, *MAJOR* patients that sustained at least 1 major complication [they may also have minor complication(s)], ODI Oswestry Disability Index, *PCS* Physical Component Score from the Medical Outcomes Short Form 36 questionnaire, *MCS* Mental Component Score from the Medical Outcomes Short Form 36 questionnaire, and the Scoliosis Research Society (SRS) 22 questionnaire

The normalization process also does not account for the non-linearity of HRQOL scales. Despite these limitations, the IHS analysis calculated changes relative to each individual patient allowing each patient to serve as their own control.

Conclusion

An integrated health state analysis suggests a significantly protracted mental recovery phase associated with patients with at least one complication in total, as well as either a minor and major complication. The addition of a reoperation also adversely affected the mental component and overall satisfaction of the recovery process.

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Conflict of interest None of the authors have a conflict of interest with this manuscript.

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