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DEFORMITY

Postoperative Recovery After Adult Spinal Deformity Surgery

Comparative Analysis of Age in 149 Patients During 2-year Follow-up

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Study Design. Retrospective review of a multicenter, prospective adult spinal deformity (ASD) database.

Objective. We hypothesized that increased age and increased preoperative disability would negatively impact both the length of time needed to achieve maximal recovery and the amount of functional improvement achieved. In order to gauge the recovery process, a normalization process was used to calculate an integrated health state (IHS) during the 2-year postoperative period.

Summary of Background Data. Elderly patients with ASD generally have worse baseline health-related quality of life (HRQOL) measures than younger patients. Current methods of reporting outcomes are limited, perhaps diminishing the health impact of the entire postoperative recovery experience.

Methods. Inclusion criteria included 18 or more years and ASD. Patient groups: young (≤45 yr), middle (46–64), elderly (≥65) as well as by baseline Oswestry Disability Index (ODI) scores: MILD (0–30), MEDIUM (31–49), and HIGH (≥50). Collected HRQOL measures included ODI, Short Form-36(PCS/MCS), and Scoliosis Research Society-22 (SRS22) at baseline, 6 weeks, 1, and 2-year postoperative. All HRQOL measures were normalized to each patient's baseline scores. A 2-year IHS was calculated for each individual patient and the means were compared between groups.

Results. 149 patients were included (≤45:32, 46–64:67, ≥65:50). All groups significantly improved in all HRQOL at 2-year compared with baseline ($P < 0.05$) except for MCS, ODI, and SRS activity for the 45 or less group ($P > 0.05$). Normalized IHS HRQOL for young patients was worse than elderly for ODI, PCS, MCS, SRS activity, pain and total during the 2-year recovery period from index surgery. The MILD ODI group had significantly worse 2-year IHS values than the HIGH group for all HRQOL measured ($P < 0.05$) except SRS appearance and satisfaction ($P > 0.05$).

Conclusion. Contrary to our hypothesis, an IHS analysis suggested that the recovery process was significantly better for elderly patients than young patients and better for patients with high baseline disability.

Key words: adult spinal deformity, age, elderly, area under the curve, integrated health state, health-related quality of life, HRQOL, disability, recovery.

Level of Evidence: 3

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Performing complicated surgical procedures in the elderly population is often very challenging as they generally have more complex spinal deformity, greater medical comorbidities, and worse bone quality than younger patients.[1–6] Furthermore, increased age is a risk factor for major complications after ASD surgery[1,3,6,7] and the effect of age on the recovery process is not well understood. And because increasing age is associated with greater baseline disability, it is also not well understood if the baseline disability apart from age is an independent risk factor for delayed recovery after surgery.

The standard method for assessing the success or failure of surgical intervention has generally been accomplished by

comparison of averages based on predefined groups between the preoperative and postoperative time points,[3,5,8–11] which does not account for individual changes. In order to increase the clinical utility of the standard HRQOL measures, both minimum clinically important difference (MCID) and substantial clinical benefit (SCB) thresholds have been determined.[10,12,13] There are still limitations with these values as they only account for differences between discreet preoperative and postoperative time points without addressing the continuum of the postoperative experience.

Thus, it is likely that the current methods of HRQOL reporting do not fully reflect the health impact of the entire postoperative recovery experience, because the changes within the postoperative period as well as fluctuations in individual HRQOL may be missed. We hypothesized that increased age and increased preoperative disability would negatively impact both the length of time needed to achieve maximal recovery and the amount of functional improvement achieved after surgery. In order to gauge the recovery process, a normalization process for HRQOL was used to calculate an integrated health state (IHS) during the 2-year postoperative period.

MATERIALS AND METHODS

Patient Population

This study is an Institutional Review Board-approved retrospective analysis of a prospective multicenter ASD database, which is composed of 11 sites across the United States. Database inclusion criteria included: age greater than or equal to 18 years and presence of spinal deformity as defined by scoliosis Cobb angle greater than or equal to 20°, sagittal vertical axis (SVA) greater than or equal to 5 cm, pelvic tilt (PT) greater than or equal to 25°, and/or thoracic kyphosis (TK) greater than or equal to 60°. Exclusion criteria included spinal deformity of a neuromuscular etiology and presence of active infection or malignancy. In addition to the criteria above, patients were included if they had complete preoperative, 6-week, 1-year, and 2-year HRQOL data recorded. This is a requirement of the IHS analysis described below.

Data Collection, Radiographical Assessment, and HRQOL

The data collected included patient age, sex, body mass index (BMI), and Charlson Comorbidity Index (CCI),[14] American Society of Anesthesiologists (ASA) physical status classification, length of hospital stay (LOS), operating room time (OR time), estimated blood loss (EBL), and complications including revisions. Patients were stratified by age groupings, which included: less than or equal to 45 (young), 46 to 64 (middle), and greater than or equal to 65 (elderly) years old.

HRQOL measures included the Oswestry Disability Index (ODI), Short-Form-36 (SF-36; Physical Component Score [PCS], and the Mental Component Score [MCS]), and Scoliosis Research Society-22 (SRS-22; total score and subdomains: activity, pain, appearance, mental, and satisfaction). 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 MICD values for the SRS subdomains included: activity (+0.375), pain (+0.587), appearance (+0.8), and mental (+0.42).[10,12,13,15]

Full-length free-standing lateral spine radiographs (36″ cassette) at baseline, 6-weeks, 1-year, and 2-year follow-up were analyzed at a central location based on standard techniques[16] using validated software[17,18] (Spineview, ENSAM, Laboratory of Biomechanics, Paris, France). These included: coronal Cobb angles, TK (T4-T12), lumbar lordosis (LL, L1-S1), C7 SVA, PT, and the mismatch between pelvic incidence (PI) and LL (PI-LL). Based on these parameters, patients were

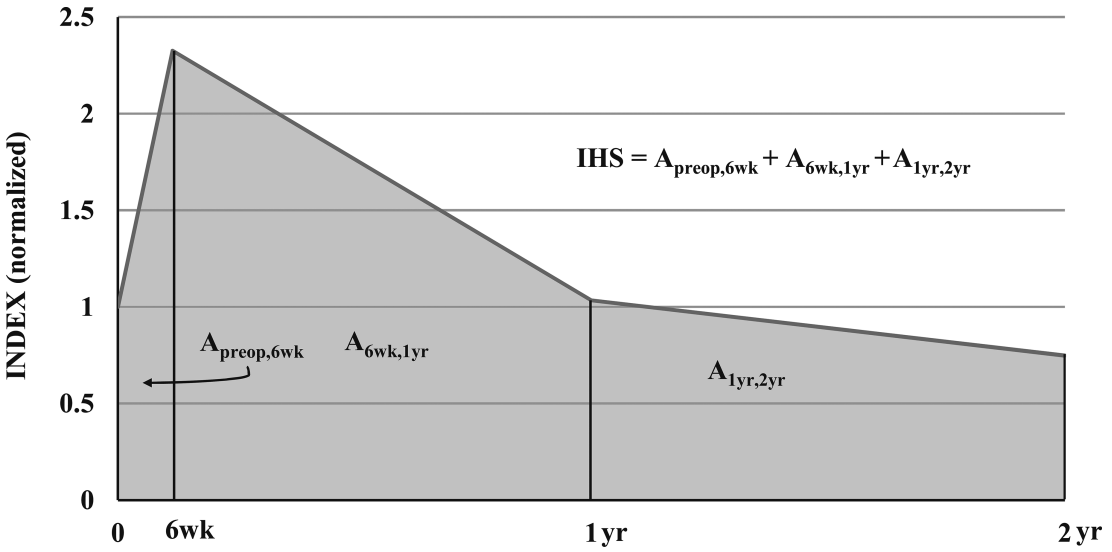

Figure 1. The integrated health state (IHS) calculation involves the summation of the areas between each time point, calculated as trapezoids. For example, the area of the first trapezoid is represented as the following: $A_{preop,6wk} = \frac{\Delta X}{2}(y_{preop} + y_{6wk})$. The y values represent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

TABLE 1. Demographic Data, Baseline SRS-Schwab Coronal Classification, and Complications Data for Age Groups

	All Patients	≤45 yr	46–64 yr	≥65 yr
Demographics				
Number	149	32	67	50
Age (yr)	56.3 ± 15.5	31.3 ± 8.2	57.3 ± 4.8	70.9 ± 4.9
Female:male (% female)	124:25 (83.2%)	27:5 (84.4%)	58:9 (86.7%)	39:11 (78.0%)
BMI	26.8 ± 6.3	24.2 ± 5.5	27.4 ± 6.9	27.7 ± 5.4
ASA	2.2 ± 0.7	1.7 ± 0.5	2.2 ± 0.6	2.6 ± 0.6
CCI	1.4 ± 1.6	0.4 ± 0.8	1.4 ± 1.5	2 ± 1.7
LOS (d)	7.8 ± 3.7	6.8 ± 3.6	7.7 ± 3.1	8.7 ± 4.4
OR time (min)	390 ± 137	295 ± 113	431 ± 130	397 ± 133
EBL (cc)	1923 ± 1749	1455 ± 1362	1877 ± 1580	2289 ± 2101
Preop SRS-Schwab Coronal Curve				
N	42 (28.6%)	3 (9.7%)	67 (56.8%)	23 (46.9%)
T	10 (6.8%)	8 (25.8%)	2 (1.7%)	0 (0%)
L	51 (34.7%)	7 (22.6%)	22 (18.6%)	22 (44.9%)
D	44 (29.9%)	13 (41.9%)	27 (22.9%)	4 (8.2%)
Complications				
Total # of complications	100 (67.1%)	18 (56.3%)	45 (67.2%)	37 (74%)
# Patients with minimum 1 intraoperative	37 (24.8%)	3 (9.4%)	18 (26.9%)	16 (32%)
# Patients with minimum 1 perioperative	63 (42.3%)	13 (40.6%)	28 (41.8%)	22 (44%)
# Patients with minimum 1 postoperative	54 (36.2%)	8 (25%)	22 (32.8%)	24 (48%)
# Patients with minimum 1 revision	25 (16.8%)	4 (12.5%)	5 (7.5%)	12 (24%)
# Patients with minimum 1 reoperations	28 (18.8%)	5 (15.6%)	11 (16.4%)	12 (24%)
# Patients with infection	13 (8.7%)	1 (3.1%)	7 (10.4%)	5 (10%)
# Patients with neurological complication	24 (16.1%)	5 (15.6%)	11 (16.4%)	8 (16%)
Number of complications				
1	44 (29.5%)	12 (37.5%)	18 (26.9%)	14 (28%)
2	25 (16.8%)	3 (9.4%)	13 (19.4%)	9 (18%)
3	13 (8.7%)	1 (3.1%)	6 (9%)	6 (12%)
4	9 (6%)	1 (3.1%)	4 (6%)	4 (8%)
5 or greater	9 (6%)	1 (3.1%)	4 (6%)	4 (8%)

For the complications data, the percentages are out of the total patients in each age group.

BMI indicates 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°.

additionally stratified by the SRS-Schwab adult spinal deformity classification.[19]

Statistical Analyses and IHS

All HRQOL measures were analyzed using the standard reported scores and normalized to each patient's baseline value. Each patient's preoperative and all postoperative scores were divided by their corresponding preoperative value resulting in normalized preoperative HRQOL values being 1. This normalization process allowed for the calculation of an IHS during the 2-year postoperative period. A line was formed by connecting all the HRQOL values and the area below

the line was calculated by summing the areas of 3 trapezoids (Figure 1). This resulted in a single value representing the total IHS across 2 years. For example, the area (*A*) between the preoperative and 6-week time points was calculated as the following: $A_{preop,6wk} = \frac{\Delta X}{2}(y_{preop} + y_{6wk})$, with ΔX being the time between measuring HRQOL values and the y values being the normalized HRQOL. ΔX was calculated as weeks and then divided by 52 weeks/year to convert the units back to years and produce reasonably sized IHS values. The 2-year IHS equation used for each patient was the following:

$$IHS_{2\,year} = \frac{\frac{6\,wk}{2}(y_{preop} + y_{6wk}) + \frac{46wk}{2}(y_{6wk} + y_{1yr}) + \frac{52wk}{2}(y_{1yr} + y_{2yr})}{52\ wk/yr}$$

IHS means for the age groups were compared. For HRQOL scores in which a higher value indicates worse outcomes (ODI), a high IHS value would indicate a poor recovery process and low IHS would indicate a good recovery process. Conversely, HRQOL in which high scores indicate better outcomes (PCS, MCS, SRS subdomains), a high IHS would indicate a good recovery process for 2 years.

Patients were also grouped based on preoperative disability as measured by ODI. MILD, MEDIUM, and HIGH ODI ranges were determined based on the average preoperative ODI for the entire group and one half of a standard deviation (SD). Therefore the MEDIUM group was based on all ODI values between the mean ± 0.5 SD. The MILD group was all patients below 0.5 SD below the mean and the HIGH group was all patients above 0.5 SD above the mean.

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 SPSS v22 (IBM, Armonk NY) with the level of significance set at $P < 0.05$.

TABLE 2. Complete Standard HRQOL for All Age Groups and Time Points

	ODI	PCS	MCS	SRS Activity	SRS Pain	SRS Appearance	SRS Mental	SRS Satisfaction	SRS Total
Preop									
All patients	40 ± 19	33 ± 10	46 ± 14	3 ± 1	2.6 ± 0.9	2.5 ± 0.7	3.5 ± 0.9	2.8 ± 1	2.9 ± 0.7
≤45 yr	24 ± 17	42 ± 10	50 ± 11	3.9 ± 0.8	3.2 ± 0.8	2.9 ± 0.5	3.7 ± 0.8	2.8 ± 1	3.4 ± 0.5
46–64 yr	43 ± 19	34 ± 9	43 ± 14	2.9 ± 0.9	2.4 ± 0.9	2.4 ± 0.8	3.3 ± 1	2.7 ± 1	2.8 ± 0.7
≥65 yr	47 ± 15	28 ± 9	47 ± 14	2.7 ± 0.9	2.3 ± 0.7	2.4 ± 0.6	3.6 ± 0.9	2.9 ± 1.1	2.8 ± 0.6
6 wk									
All patients	46 ± 19	30 ± 9	46 ± 14	2.6 ± 0.7	2.4 ± 0.8	3.5 ± 0.9	3.6 ± 0.9	4.1 ± 0.9	3.1 ± 0.6
≤45 yr	37 ± 19	34 ± 10	47 ± 13	2.7 ± 0.8	2.5 ± 1	3.8 ± 0.8	3.8 ± 0.7	4.1 ± 0.9	3.3 ± 0.6
46–64 yr	50 ± 17	29 ± 8	45 ± 14	2.4 ± 0.7	2.2 ± 0.7	3.4 ± 0.9	3.4 ± 0.9	4.2 ± 0.9	3 ± 0.6
≥65 yr	46 ± 19	30 ± 9	47 ± 13	2.8 ± 0.8	2.5 ± 0.8	3.4 ± 0.9	3.6 ± 0.9	4.1 ± 0.9	3.2 ± 0.7
1 yr									
All patients	28 ± 19	41 ± 11	50 ± 13	3.5 ± 1	3.4 ± 1	3.7 ± 0.9	3.9 ± 0.9	4.3 ± 0.9	3.7 ± 0.8
≤45 yr	19 ± 18	48 ± 10	51 ± 10	4 ± 0.9	3.7 ± 1.1	4 ± 0.9	4 ± 0.8	4.4 ± 0.8	4 ± 0.7
46–64 yr	29 ± 19	41 ± 10	48 ± 16	3.3 ± 1	3.2 ± 1	3.6 ± 0.9	3.7 ± 1	4.2 ± 1.1	3.5 ± 0.9
≥65 yr	32 ± 20	37 ± 9	53 ± 12	3.5 ± 0.8	3.4 ± 1	3.6 ± 0.8	4 ± 0.9	4.3 ± 0.8	3.7 ± 0.7
2 yr									
All patients	25 ± 20	41 ± 11	51 ± 13	3.6 ± 1	3.5 ± 1.1	3.7 ± 0.9	3.9 ± 0.9	4.3 ± 0.9	3.7 ± 0.8
≤45 yr	17 ± 18	47 ± 11	50 ± 13	4.2 ± 0.9	3.7 ± 0.9	4.1 ± 0.8	4.1 ± 0.8	4.3 ± 0.7	4 ± 0.7
46–64 yr	26 ± 21	42 ± 11	49 ± 14	3.5 ± 1	3.3 ± 1.1	3.7 ± 1	3.7 ± 1	4.2 ± 1	3.6 ± 0.9
≥65 yr	30 ± 20	36 ± 10	53 ± 11	3.5 ± 0.9	3.5 ± 1.1	3.5 ± 0.8	4 ± 0.8	4.3 ± 0.9	3.7 ± 0.7

Values are presented as the mean ± 1 standard deviation.

MCS indicates Mental Component Score of the SF-36; ODI, Oswestry Disability Index; PCS, Physical Component Score of the SF-36; SRS, Scoliosis Research Society-22 questionnaire.

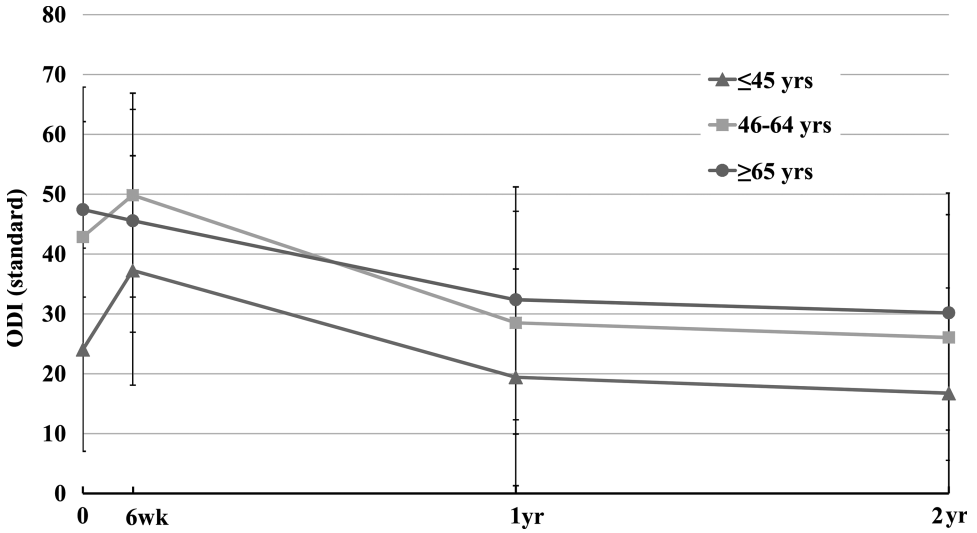

Figure 2. Standard Oswestry Disability Index (ODI) for all age groups across 2 yr. Error bars denote ± 1 standard deviation.

RESULTS

Patient Population

286 patients were eligible and 235 (82.2%) had complete baseline and 2-year clinical and radiographical follow-up. Of those, 149 (63.4%) had complete preoperative, 6-week, 1, and 2-year HRQOL and were analyzed. The mean age was 56.3 ± 15.5 years and there were 124 females and 25 males (Table 1). There were 32 young (≤45 yr) patients, 67 middle-aged (46–64 yr), and 50 elderly (≥65 yr). The middle and elderly groups had significantly higher preoperative BMI, ASA, CCI, LOS, OR time, and EBL than the young ($P < 0.05$ for all, Table 1) with the exception of EBL for young *versus* middle ($P > 0.05$). As the patient age groups increased, the distribution of the preoperative SRS-Schwab coronal curve types shifted from predominately coronal curves (Types T, L, and D) in the young to predominately Type N and L in the elderly ($P < 0.05$ for all comparisons, Table 1).

Complications

The elderly patients had a significantly higher percentage of patients that sustained both intraoperative and postoperative complications compared with the young ($P < 0.05$ for all, Table 1). The elderly also had a significantly higher percentage of patients that underwent a revision compared with the middle age group ($P < 0.05$, Table 1).

Standard HRQOL

The middle and elderly groups had significantly worse preoperative ODI, PCS, SRS activity, pain and total scores than the young ($P < 0.05$ for all, Table 2, Figures 2 and 4). Only preoperative PCS was significantly worse for the elderly *versus* middle age ($P < 0.05$ for both). All age groups significantly improved in all standard HRQOL at 2 years compared with preoperative values ($P < 0.05$ for all), with the exception of ODI, MCS, and SRS activity for the young ($P > 0.05$ for all).

Normalized HRQOL

The elderly patients had significantly better normalized 6-week ODI (Figure 3), PCS, SRS activity (Figure 5), pain, and total score, better 1-year MCS, PCS, SRS activity, and pain as well as better 2-year MCS, SRS activity, pain, and total score than the young ($P < 0.05$ for all, Table 3). The elderly also had better 6-week PCS, SRS activity, and 1-year

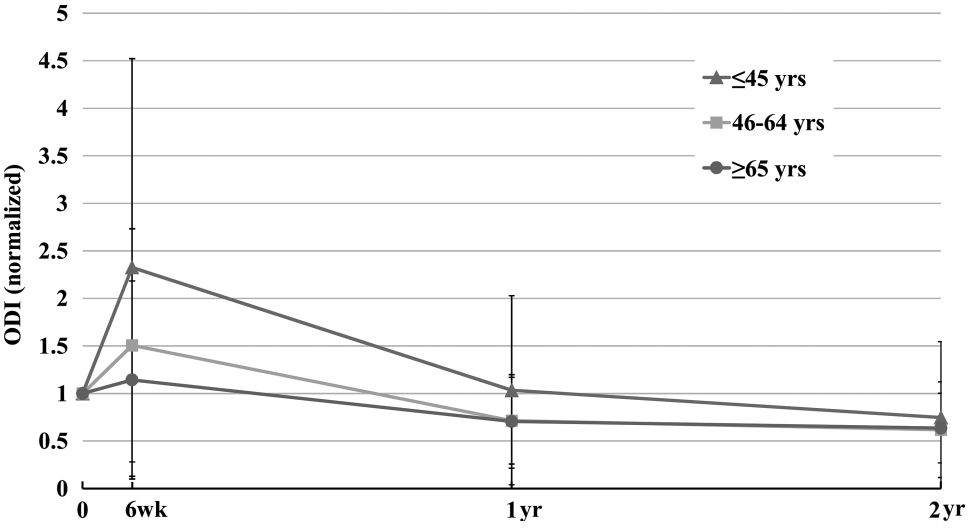

Figure 3. Normalized Oswestry Disability Index (ODI) for all age groups across 2 yr. ODI is an example of large area under the curve (IHS) values indicating a poor recovery experience *vs* smaller values indicating a better recovery experience. Error bars denote ± 1 standard deviation.

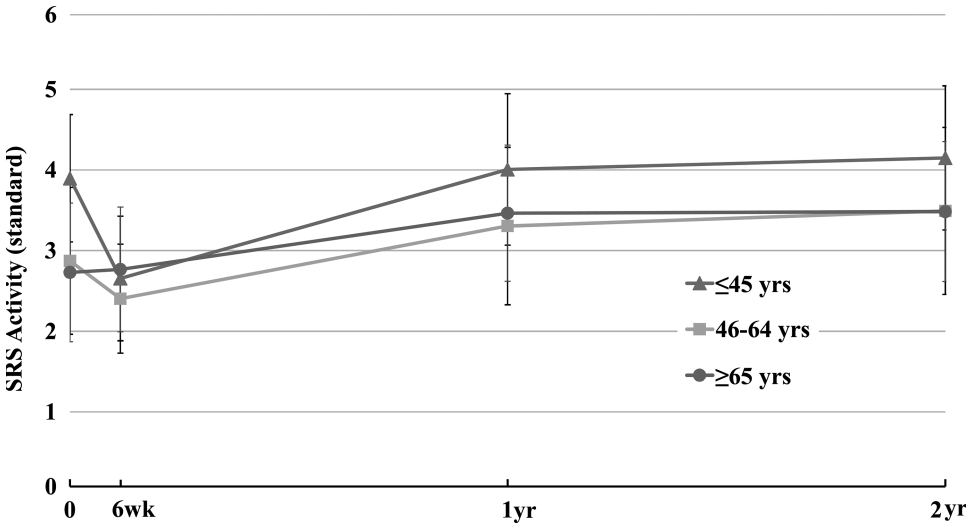

Figure 4. Mean standard Scoliosis Research Society (SRS) 22 Activity scores for all age groups across 2 yr. Error bars denote ± 1 standard deviation.

PCS than the middle age group ($P < 0.05$ for all), however no differences were seen at 2-years between the elderly and middle age. The middle age group had better normalized 6-week MCS, SRS activity, pain and total as well as 1 and 2-year SRS activity than the young.

IHS

The middle age and elderly patients had a significantly larger IHS for MCS, SRS activity (Figure 5), pain, and total score than the young patients ($P < 0.05$ for all, Table 4). Furthermore, the elderly group had a significantly smaller IHS for ODI and larger IHS for PCS than the young patients ($P < 0.05$ Table 4). There were no significant differences in any IHS values between the elderly and middle age group ($P > 0.05$ Table 4).

The average preoperative ODI (±1 SD) for the entire cohort was 40.5 ± 19.3. Therefore the preoperative disability groups based on the mean ± 0.5 SD were determined to be the following: MILD (0–30), MEDIUM (31–49), and HIGH (≥50) (Table 5). The HIGH group had significantly better 2-year IHS values than the MILD group for all HRQOL measured ($P < 0.05$ for all, Table 5, Figures 6 and 7) with the exception of SRS appearance and satisfaction ($P > 0.05$ for both). In addition, the MEDIUM group had significantly better IHS values compared with the MILD group for all HRQOL measured ($P < 0.05$ for all, Table 5, Figures 6 and 7) except SRS mental and satisfaction ($P > 0.05$ for both). And lastly, the HIGH group had significantly better IHS values than the MEDIUM group for SRS activity, mental and pain ($P < 0.05$ for all, Table 5).

MCID and SCB

As age increased, patients were more likely to reach MCID however, the elderly group had a significantly higher percentage of patients meeting 2-year MCID for SRS activity compared with the young ($P < 0.05$ for both, Table 4). All other MCID and SCB comparisons between age groups did not reach statistical significance ($P > 0.05$ for all).

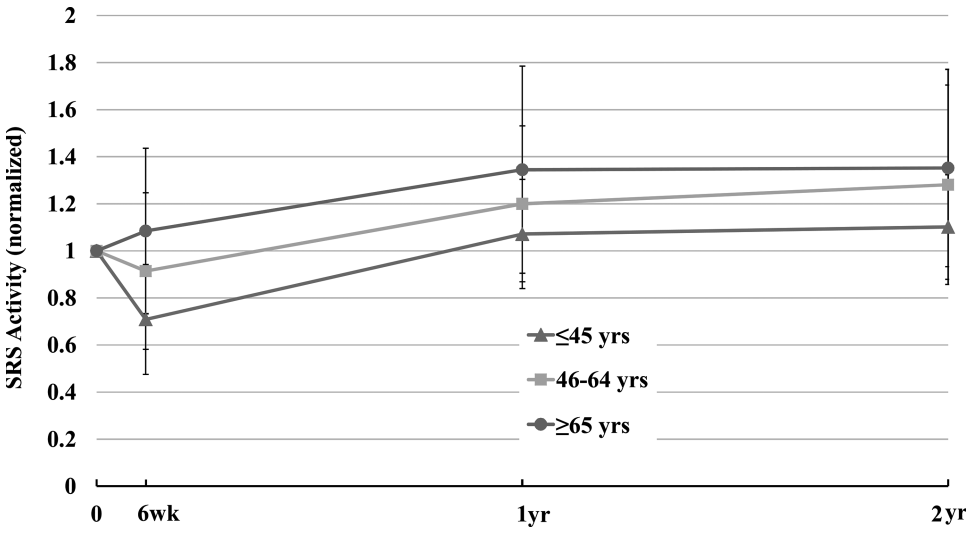

Figure 5. Mean normalized Scoliosis Research Society (SRS) 22 Activity scores for all age groups across 2 yr. The SRS-22 is an example of large area under the curve (IHS) values indicating a better recovery *vs* smaller values indicating a poor recovery experience. Error bars denote ± 1 standard deviation.

TABLE 3. Complete Normalized HRQOL for All Age Groups and Time Points

	ODI	PCS	MCS	SRS Activity	SRS Pain	SRS Appearance	SRS Mental	SRS Satisfaction
Preop								
All patients	1	1	1	1	1	1	1	1
≤45 yr	1	1	1	1	1	1	1	1
46–64 yr	1	1	1	1	1	1	1	1
≥65 yr	1	1	1	1	1	1	1	1
6-wk								
All patients	1.5 ± 1.5	1 ± 0.4	1.1 ± 0.4	0.9 ± 0.3	1.1 ± 0.5	1.5 ± 0.6	1.1 ± 0.2	1.8 ± 1.1
≤45 yr	2.3 ± 2.2	0.9 ± 0.3	0.9 ± 0.2	0.7 ± 0.2	0.8 ± 0.3	1.4 ± 0.3	1 ± 0.2	1.8 ± 1.2
46–64 yr	1.5 ± 1.2	0.9 ± 0.4	1.1 ± 0.5	0.9 ± 0.3	1.1 ± 0.5	1.6 ± 0.8	1.1 ± 0.3	1.8 ± 1.1
≥65 yr	1.1 ± 1	1.1 ± 0.4	1.1 ± 0.4	1.1 ± 0.4	1.2 ± 0.5	1.5 ± 0.5	1.1 ± 0.3	1.7 ± 1.1
1-yr								
All patients	0.8 ± 0.6	1.3 ± 0.5	1.2 ± 0.5	1.2 ± 0.4	1.4 ± 0.5	1.6 ± 0.6	1.1 ± 0.3	1.8 ± 1
≤45 yr	1 ± 1	1.2 ± 0.4	1 ± 0.3	1.1 ± 0.2	1.2 ± 0.3	1.4 ± 0.4	1.1 ± 0.2	1.9 ± 1.1
46–64 yr	0.7 ± 0.5	1.2 ± 0.4	1.2 ± 0.6	1.2 ± 0.3	1.5 ± 0.7	1.6 ± 0.7	1.2 ± 0.3	1.8 ± 1.1
≥65 yr	0.7 ± 0.5	1.5 ± 0.6	1.3 ± 0.4	1.3 ± 0.4	1.5 ± 0.5	1.6 ± 0.6	1.2 ± 0.3	1.8 ± 0.9
2-yr								
All patients	0.7 ± 0.5	1.3 ± 0.5	1.2 ± 0.5	1.3 ± 0.4	1.5 ± 0.6	1.6 ± 0.7	1.2 ± 0.3	1.8 ± 1.1
≤45 yr	0.7 ± 0.8	1.2 ± 0.3	1 ± 0.3	1.1 ± 0.2	1.2 ± 0.3	1.5 ± 0.4	1.1 ± 0.2	1.8 ± 1.1
46–64 yr	0.6 ± 0.5	1.3 ± 0.4	1.2 ± 0.5	1.3 ± 0.4	1.5 ± 0.7	1.7 ± 0.8	1.2 ± 0.3	1.8 ± 1.1
≥65 yr	0.6 ± 0.4	1.5 ± 0.7	1.3 ± 0.6	1.4 ± 0.4	1.6 ± 0.6	1.6 ± 0.6	1.2 ± 0.4	1.8 ± 1

Values are presented as the mean ± 1 standard deviation.

MCS indicates Mental Component Score of the SF-36; ODI, Oswestry Disability Index; PCS, Physical Component Score of the SF-36; SRS, Scoliosis Research Society-22 questionnaire.

DISCUSSION

Contrary to our study hypothesis and based on individual normalized HRQOL scores producing an IHS, we determined that the recovery processes were significantly worse for younger patients than the elderly patients. Elderly patients had a shorter and improved recovery period compared with younger patients when normalized to their own preoperative baseline values despite a higher complication rate. In addition, patients with high preoperative disability independent of age also had a better recovery process than those with lower baseline disability when patients are normalized to their baseline scores. MCID and SCB rates were similar between age groups indicating these assessment measures may be missing components of the recovery process.

The normalized HRQOL analysis provides some insight into the recovery process differences. The majority of the significant differences between age groups were seen at the 6-week time point where the younger patients had a large increase in disability and decrease in health status when normalized to their baseline values. The effect was reduced as the age groups increased in age (Figure 3). Because the 6-week normalized time point was the most affected, this resulted in the elderly having spent less time with poor HRQOL during the 2 years compared with the young. Moreover, a few of the normalized HRQOL values at 2 years were significantly better in the elderly than the young patients (MCS, SRS activity, pain, and total) indicating they had larger improvements in those domains than the young patients when compared with their baseline scores.

Patients with worse baseline disability had a better recovery process than those with lower baseline disability when compared with their baseline values. This was independent of age, however, baseline disability and age are very closely related as evidenced by the present study and others.[2,20] The disability groups were skewed in terms of the age distributions between them. It is difficult to separate these variables however, this is the first analysis to indicate that disability may be a larger driver behind the improved recovery process than once thought and less depending on age itself. However, because they are so closely related, it is very difficult to

TABLE 4. Complete IHS Values as well as the Number and Percentage of Patients Meeting Minimum Clinically Important Difference (MCID) and Substantial Clinical Benefit (SCB) for All Age Groups Across 2 Yr

	All Patients	≤45 Yr	46–64 Yr	≥65 Yr
Integrated Health States				
ODI	1.9 ± 1.4	2.7 ± 2.2	1.8 ± 1.1	1.6 ± 0.9
PCS	2.5 ± 0.8	2.3 ± 0.6	2.4 ± 0.7	2.7 ± 1
MCS	2.3 ± 0.8	2 ± 0.5	2.4 ± 1	2.4 ± 0.6
SRS activity	2.3 ± 0.6	2 ± 0.4	2.3 ± 0.6	2.5 ± 0.7
SRS pain	2.7 ± 0.9	2.3 ± 0.6	2.8 ± 1.1	2.8 ± 0.8
SRS appearance	3.1 ± 1.2	2.8 ± 0.7	3.3 ± 1.4	3.1 ± 1
SRS mental	2.2 ± 0.5	2.2 ± 0.4	2.3 ± 0.5	2.3 ± 0.5
SRS satisfaction	3.6 ± 2	3.6 ± 2.1	3.7 ± 2	3.5 ± 1.9
SRS total	2.5 ± 0.6	2.3 ± 0.4	2.6 ± 0.7	2.6 ± 0.5
MCID				
ODI	70 (47.9%)	11 (35.5%)	34 (52.3%)	25 (50%)
PCS	70 (54.7%)	12 (46.2%)	32 (56.1%)	26 (57.8%)
SRS activity	95 (65.1%)	15 (48.4%)	42 (63.6%)	38 (77.6%)
SRS pain	100 (68.5%)	21 (67.7%)	44 (66.7%)	35 (71.4%)
SRS appearance	105 (72.4%)	24 (77.4%)	49 (74.2%)	32 (66.7%)
SRS mental	60 (41.4%)	14 (45.2%)	29 (43.9%)	17 (35.4%)
SCB				
ODI	59 (40.4%)	9 (29%)	30 (46.2%)	20 (40%)
PCS	66 (51.6%)	12 (46.2%)	30 (52.6%)	24 (53.3%)

Values are presented as the mean ± 1 standard deviation.

MCS indicates Mental Component Score of the SF-36; ODI, Oswestry Disability Index; PCS, Physical Component Score of the SF-36; SRS, Scoliosis Research Society-22 questionnaire.

determine the stronger driver. More work into this type of analysis is needed.

The differences in normalized HRQOL and thus, IHS values, may be due to 2 different reasons. The first being the elderly patients having higher preoperative disability, which is in line with prior studies.[2,11,20,21] In addition, the baseline coronal curve types differed between the age groups with more coronal curves (Type T and Type D) in younger patients and more Type N (no significant coronal curves) in the elderly patients. This is in line with Fu *et al*[22] in which younger patients had similar sagittal malalignment to a nonoperative cohort and the elderly had greater preoperative sagittal malalignment. This may explain some of the lower preoperative disability in younger patients as sagittal malalignment has been repeatedly shown to be a strong driver of disability.[15,21,23–26] Bess *et al*[2] determined operative management in young adults was driven by increased coronal plane deformities whereas pain and disability were the dominant factors in the elderly.

These findings may have a large effect on the recovery process of the age groups. Because the younger patients had higher baseline function and less disability than the elderly patients, the surgery may have had a larger impact on their function in the early postoperative period thus worsening their normalized HRQOL at 6-weeks resulting in worse IHS values. In contrast, the elderly patients had poor baseline function and high disability. Thus, a large surgery may have not impacted their function as much when normalized to baseline and thus their early postoperative HRQOL did not have as large of a relative change. In many cases it already decreased by the 6-week time point. In addition, based on prior work, they were also probably more likely to choose surgery due to disability[2] so their perception of disability may be different than younger patients.

The second reason may be due to the elderly patients having a greater number of complications (intra- and postoperative) compared with the young patients. This result may have a similar explanation to the one above regarding the elderly

TABLE 5. The Number and Percentage of Patients in Each of the Preoperative Oswestry Disability Index (ODI) Groups as Well as the Complete IHS Values for All Preoperative ODI Groups Across 2 Yr

Preoperative Disability Groups	All Patients	≤45 Yr	46–64 Yr	≥65 Yr
Low ODI (0–30)	45 (100%)	19 (42.2%)	18 (40%)	8 (17.8%)
Medium ODI (31–49)	51 (100%)	8 (15.7%)	26 (51%)	17 (33.3%)
High ODI (≥50)	52 (100%)	4 (7.7%)	23 (44.2%)	25 (48.1%)
Integrated Health States	**All patients**	**Low ODI (0–30)**	**Medium ODI (31–49)**	**High ODI (≥50)**
ODI	1.9 ± 1.4	3 ± 2	1.5 ± 0.7	1.5 ± 0.4
PCS	2.5 ± 0.8	2.1 ± 0.6	2.5 ± 0.7	2.8 ± 1
MCS	2.3 ± 0.8	2 ± 0.3	2.4 ± 0.7	2.5 ± 1.1
SRS activity	2.3 ± 0.6	1.9 ± 0.4	2.3 ± 0.5	2.7 ± 0.7
SRS pain	2.7 ± 0.9	2.2 ± 0.6	2.6 ± 0.8	3.2 ± 1.1
SRS appearance	3.1 ± 1.2	2.8 ± 0.8	3.1 ± 1	3.4 ± 1.4
SRS mental	2.2 ± 0.5	2.1 ± 0.3	2.2 ± 0.4	2.4 ± 0.6
SRS satisfaction	3.6 ± 2	3.4 ± 1.7	3.8 ± 2.2	3.6 ± 2
SRS total	2.5 ± 0.6	2.2 ± 0.3	2.5 ± 0.4	2.8 ± 0.7

The percentages were calculated out of the total patients in each group to provide the distribution of the ages within each group. The IHS values are presented as the mean ± 1 standard deviation.

PCS indicates Physical Component Score of the SF-36; SRS, Scoliosis Research Society-22 questionnaire.

patients having higher baseline disability. As the elderly patients had more disability than the younger patients, having a complication may not have affected their perception of disability as much. Thus, their HRQOL did not decrease as much and their IHS values were better.

The strengths of the current study include the multicenter design, and the complete preoperative, 6-week, 1-year and 2-year follow-up of the patients assessed. Furthermore, patients were enrolled from multiple surgeons comprising 11 different sites across the United States, which allows for better generalizability of the results. However, there are a few limitations to this study, one of which includes the retrospective design. Despite the retrospective nature, the data used was obtained from a large multicenter prospective database. Another limitation is the requirement of the IHS calculation that patients must have HRQOL measurements at all the listed time points. This reduces the sample size available for analysis as full compliance follow-up is difficult.

The HRQOL normalization process has inherent limitations. This method has all patients starting at a value of 1,

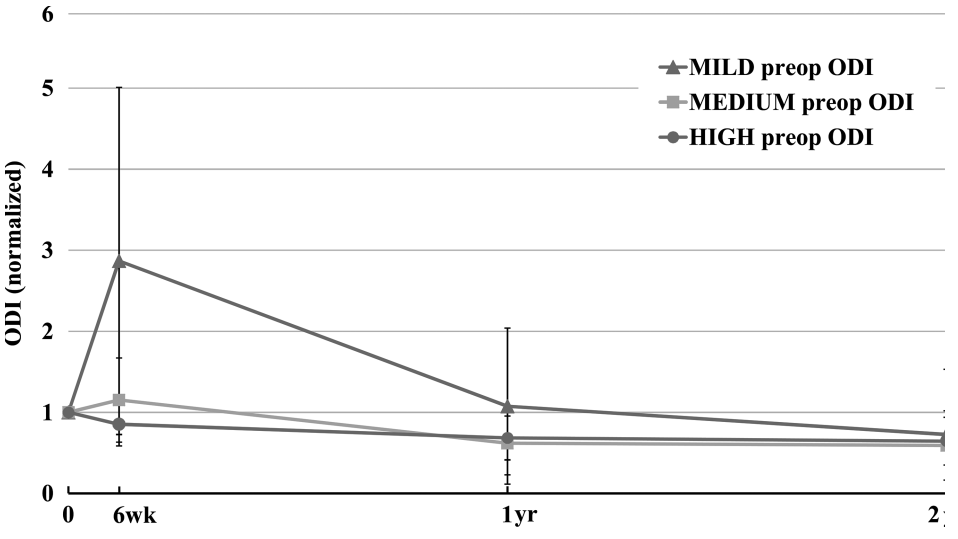

Figure 6. Normalized Oswestry Disability Index (ODI) for patients based on preoperative disability determined by ODI scores. ODI is an example of large area under the curve (IHS) values indicating a poor recovery experience *vs* smaller values indicating a better recovery experience. Error bars denote ± 1 standard deviation. MILD indicates patients with preoperative ODI between 0 and 30; MEDIUM, patients with preoperative ODI between 31 and 49; and HIGH, patients with preoperative ODI ≥ 50.

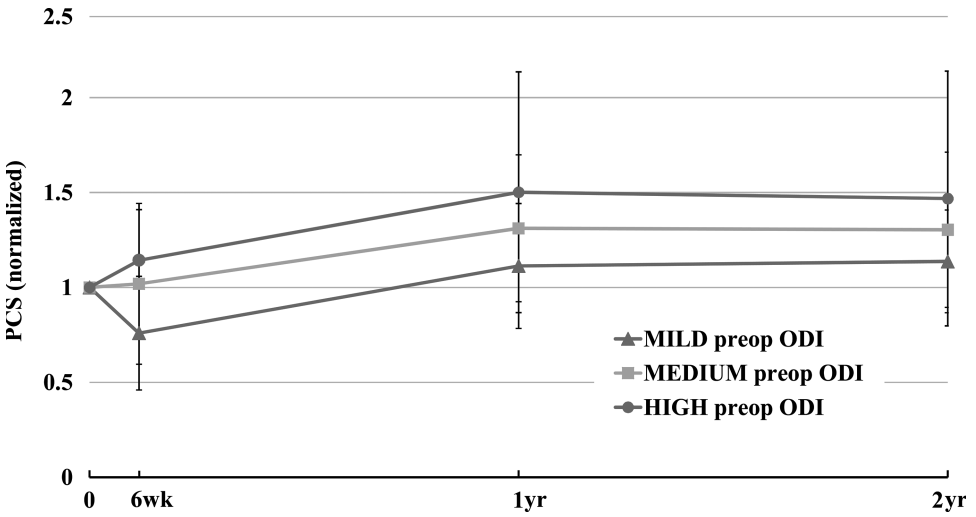

Figure 7. Normalized Physical Component Score (PCS) form the Short Form-36 survey for patients based on preoperative disability determined by Oswestry Disability Index (ODI) scores. ODI is an example of large area under the curve (IHS) values indicating poor recovery experience than smaller values. Error bars denote ± 1 standard deviation. MILD indicates patients with preoperative ODI between 0 and 30; MEDIUM, patients with preoperative ODI between 31 and 49, and HIGH, patients with preoperative ODI ≥ 50.

which neglects individual baseline differences in HRQOL. We are aware that this is not the case and there is significant heterogeneity to baseline values for numerous reasons. The normalization process also does not account for the non-linearity of the HRQOL scales. The IHS analysis was patient specific as the changes were calculated relative to each individual patient, thus baseline differences are less important as each patient served as their own control. Furthermore, data points between 6-weeks and 1-year postoperative were lacking and thus, the analysis assumes the recovery process is linear during these time points. This may not be true and more data and very close follow-up is required to address this issue. This analysis is novel and the first to attempt the quantitative assessment of the recovery process after ASD surgery. Future work is necessary to investigate the use of IHS calculations as we describe the recovery process in ASD.

➢ Key Points

- ❑ Based on standard HRQOL analysis, elderly patients had worse preoperative HRQOL than younger patients and all age groups had improved HRQOL at 2 years after surgery.
- ❑ At 6 weeks postoperative, younger patients and those with low baseline disability had a large increase in disability and decrease in health status when normalized to their baseline values.
- ❑ Integrated health state analysis suggested that the recovery process was significantly worse for younger patients than the elderly patients and worse for patients with low baseline disability.
- ❑ Both elderly patients and those with high preoperative baseline disability had a shorter and improved recovery period compared with younger patients or patients with low baseline disability when normalized to their own preoperative baseline values.

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