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DEFORMITY

Group-based Trajectory Modeling: A Novel Approach to Classifying Discriminative Functional Status Following Adult Spinal Deformity Surgery

Study of a 3-year Follow-up Group

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Study Design. Retrospective review of prospectively collected database.

Objective. To delineate and visualize trajectories of the functional status in surgically-treated adult spinal deformity (ASD) patients.

Summary of Background Data. Classifying long-term recovery following ASD surgery is not well defined.

Methods. One thousand one hundred seventy-one surgically-treated patients with a minimum of 3-year follow-up were included. The group-based trajectory modeling (GBTM) was used to identify distinct trajectories of functional status over time, measured by Oswestry Disability Index (ODI). Patient profiles were then compared according to the observed functional patterns.

Results. The GBTM identified four distinct functional patterns. The first group (10.0%) started with minimal disability (ODI: 15 ± 10) and ended up almost disability-free (low-low). The fourth group (21.5%) began with high ODI (66 ± 11) and improvement was minimal (high-high). Groups two (40.1%) and three (28.4%) had moderate disability (ODI: 39 ± 11 *vs.* 49 ± 11, $P < 0.001$) before surgery. Following surgery, marked improvement was seen in group two (median-low), but deterioration/no change was observed in group three (median-high). The low-low group primarily included adult idiopathic scoliosis, while the high-high group had the oldest and the most severe patients as compared with the rest of the groups. A subgroup analysis was performed between groups two and three with propensity score matching on age, body mass index, baseline physical component score (PCS), and severity of deformity. Notably, the baseline mental status of the median-high group was significantly worse than that of the median-low group, though the differences in demographics, surgery, and deformity no longer existed.

Conclusion. Patients with moderate-to-low disability are more likely to obtain better functional postoperative outcomes. Earlier surgical interventions should be considered to prevent progression of deformity, and to optimize favorable outcomes. Greatest improvement appears to occur in moderately disabled patients with good mental health. GBTM permits classification into distinct groups, which can help in surgical decision making and setting expectations regarding recovery.

Key words: adult spinal deformity, functional status, group-based trajectory modeling, Oswestry disability index (ODI).

Level of Evidence: 3

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The prevalence of adult spinal deformity (ASD) increases with age from 3.14% in those aged between 40 and 49, to 10.95% in those aged between 60 and 69, and 50% in those aged ≥90 years.[1] Functional limitations in daily activities, chronic pain, as well as dysfunction in social life are commonly observed in patients with ASD.[2] Moreover, previous studies have shown that ASD patients were more likely to have issues with mental health, financial difficulties due to absence from work, and family problems compared with healthy or asymptomatic controls.[3,4]

Chronic pain and loss of function are the major reasons that ASD patients seek medical attention.[5] Although the treatment of ASD is the subject of much debate, an increasing number of patients are opting for surgery.[6] The goals of operative treatment are to prevent further progression of the deformity, restore sagittal and coronal alignment, relieve neurological symptoms, and optimize cosmesis.[7] However, surgical approaches to treatment of ASD can be complex due not only to the spinal deformity but also due to the need to account for patient symptoms, disability, and perioperative comorbidities. These procedures have been reported to have a considerable rate of complications and a broad range of outcomes.[8–10] Hence, classifying patients by their recovery patterns and long-term outcomes is of particular importance for targeting treatment goals and expectations.

When evaluating patient functional performance during the postoperative recovery period, the Oswestry Disability Index (ODI), which is a spine disease-specific health-related quality-of-life (HRQOL) measure, has been widely used.[11] Changes in ODI scores (Δ ODI) postsurgery are monitored to determine the effectiveness of treatment strategies. However, the problem with this evaluation approach is that it may mask important recovery heterogeneity among ASD patients or the existence of groups of patients whose treatment has a distinct impact on functional limitations and long-term outcomes, despite similar changes in overall ODI scores. For example, identical Δ ODI values may be calculated for patients with 1) severe disability preoperatively, but with intermittent disability throughout follow-up, or 2) with intermittent disability before surgery but normal functional status after surgery. These differences are poorly captured by before-and-after comparison but can have important implications for patient recovery, particularly when functional status is assessed over longer time periods. Even more significantly, patients can start with the same level of disability but end up with distinct functional limitations following surgery. It is difficult to differentiate those patients unless individual trajectory of functional status over time was captured.

Group-based trajectory models (GBTMs) may provide an alternative methodology for summarizing long-term functional recovery while accounting for the dynamic nature of recovery over time.[12] These models estimate the change over time for repeatedly measured outcomes, which therefore are able to identify individuals who have similar longitudinal response patterns. The purpose of the present study was to classify ASD patients by their long-term functional status after spinal surgery using GBTM and to analyze differences in patient characteristics across defined groups.

MATERIALS AND METHODS

Patient Population

The present study is a retrospective review of prospectively collected multicenter database that includes patients enrolled at 11 sites across United States. Inclusion criteria of the database were age $\geq$ 18 years and presence of spinal deformity, which is defined by at least one of the following conditions: scoliosis with a Cobb angle $\geq$20°, sagittal vertical axis (SVA) length $\geq$5 cm, pelvic tilt (PT) angle $\geq$25°, and/or thoracic kyphosis (TK) angle $\geq$60°. Patients who had active infection, malignancy or whose spinal deformity was due to neuromuscular conditions were excluded. Patient demographics, comorbidities, radiographic parameters, perioperative information, and HRQOL measures were obtained at baseline and each annual follow-up, depending on the study protocol. Standing postero-anterior and lateral spine radiographs were analyzed using validated software[13,14] (Spineview; Laboratory of Biomechanics, ParisTech, Paris, France) to obtain radiographic parameters, including T1 pelvic angle (T1PA), pelvic tilt (PT), pelvic incidence (PI), PI and lumbar lordosis mismatch (PI-LL), and sagittal vertical axis (SVA).

At the time of enrollment, patients were divided into operative and nonoperative groups according to their initial treatment plan. The present study only included surgically-treated ASD patients with a minimum of 3-year follow-up after spinal surgery.

Oswestry Disability Index (ODI)

The ODI score of each patient was obtained at both baseline and annual follow-up visits. It assesses perceived level of disability in 10 activities of daily living, including pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sex life, social life, and traveling. Each section includes six items scored from 0 to 5 with higher scores indicting worse outcomes.

Statistical Analysis

GBTMs were performed to classify ASD patients by their observed functional status over time following surgery. The strength of GBTMs over conventional longitudinal analysis is its capacity to identify the heterogeneity of the population or distinct subgroups that show similar patterns in a longer period. In other words, the categorization of patient groups was data driven, rather than being grouped with clinical considerations. Because GBTM is primarily deal with longitudinal data, it is not immune to missing data issues. However, GBTM can provide parameters estimates that are asymptotically unbiased when the data are missing at random (MAR),[15] which is the scenario in the present study. That is, there might be systematic differences between the missing and observed data, but these can be entirely explained by other observed variables.[16] GBTM used full-information maximum likelihood (FIML) estimation to integrate all available information on the basis of MAR assumptions.[15] We applied the user-written packages called "Traj" in Stata SE 14.0 (StataCorp, College Station, TX) to identify these latent trajectories.[17] In a GBTM, multiple regression models are estimated simultaneously through maximization of a likelihood that combines the information from all models. That is, each patient is assumed to belong to a single subgroup for the duration of study follow-up, based on patient functional patterns over time. Within each functional group, functional status was modeled as a smooth function of time using up to a fourth-order polynomial. Hence, the model assumes that repeated measures on the same patient are independent conditionals of a trajectory group. We examined solutions with two to six subgroups and allowed for quadratic trajectories within each subgroup, though models with linear trajectories were ultimately used based on the data. Three criteria were applied to identify the optimal number of subgroups. First, we compared the value of Bayesian Information Criterion (BIC) iteratively across models with different numbers of groups. Second, the average probability of belonging to each group (average posterior probability) using a minimum threshold of 70 was examined.[15] Lastly, the number of patients in each group and the relevance of clinical interpretation were also considered. Ultimately, a model with four subgroups was chosen based on both statistical and clinical considerations. The demographic, surgical, and radiographic characteristics were then compared across these four subgroups using Student *t* test for normally distributed continuous variables, Wilcoxon Rank-Sum test for non-normally distributed continuous variables, and chi-squared test for categorical variables.

RESULTS

In total, 1171 surgically-treated ASD patients were included in the current study with up to 3-year follow-up. The follow-up rate at each time point was 86.7% at 1 year, 73.5% at 2 year, and finally 49.8% at 3 years. The GBTMs identified four distinct functional trajectories based on observed ODI over time (Figure 1). The patients in first group (N = 117, 10.0%) started with minimal disability (ODI: 15 ± 10) and ended up almost disability-free (low-low). The patients in the fourth group (N = 252, 21.5%) had the most severe disability, starting with a high mean ODI (66 ± 11), but their improvement was relatively minimal (high-high). Notably, groups two (N = 469, 40.1%) and three (N = 333, 28.4%) had similar baseline mean ODI values, both consistent with moderate disability (ODI: 39 ± 11 *vs.* 49 ± 11, $P < 0.001$) before surgery. However, following the surgery, a large improvement was seen in group two (median-low), but a deterioration/no change was observed in group three (median-high).

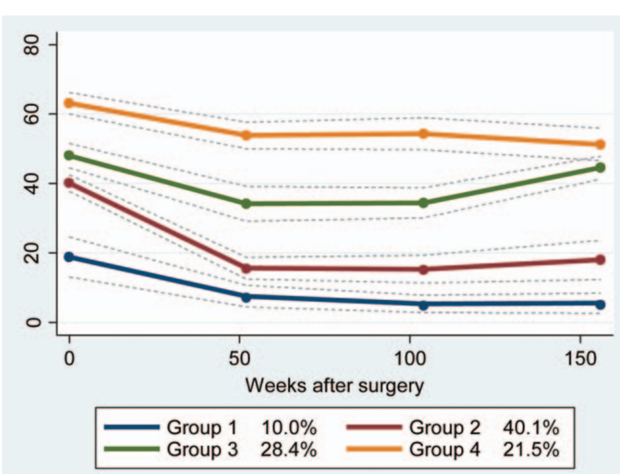

Figure 1. Group trajectories of ODI over study follow-up. ODI indicates Oswestry Disability Index.

Patient demographic and comorbidities (Table 1), baseline patient-reported outcomes, and radiographic parameters (Table 2) were then evaluated across the four subgroups in order to determine their profiles. The low-low group primarily consisted of adult idiopathic scoliosis patients who were the youngest, with the least comorbidities, lowest pain intensity, and the best patient-reported outcome measures (PROMs), compared with the other patient groups. In contrast, the high-high group included patients who were the oldest, had the most severe deformity, the highest level of pain intensity, the worst preoperative/postoperative PROMs, and the highest complication rates, including both major and minor, as compared with the rest of the groups. The median-high group included patients who were older, had poorer sagittal alignment and worse PROMs than those in the median-low group. However, no difference was found with respect to the types of surgery across the four groups, except that the high-high group had longer average operative time.

Functional subgroup were also compared in terms of 1 year outcome (radiographic and patient reported outcome) (Table 3), rate of patient reach a Minimal Clinically Important Difference (MCID) between pre and 1-year postop (Table 4), and finally patient-reported outcome at 2-year postop (Table 5). Results demonstrated better patient-reported outcome at 1-year and 2-year for low-low and median-low and a greater proportion of patient reaching an MCID for median-low group. High-high group demonstrated worst postoperative outcome as well as smaller rate of improvement.

In order to further identify the factors that differentiate recovery patterns between groups two and three, a subanalysis was performed between these two groups with propensity score matching based on age, body mass index, baseline SF-36 physical component score (PCS), PI-LL mismatch, and T1PA. It was worth noting that the mental health status of the median-high group was significantly worse than that of the median-low group (SRS mental health: 3.2 *vs.* 3.5, $P = 0.019$; SF-36 mental score: 41.8 *vs.* 45.1, $P = 0.042$), while no statistically significant difference was observed with respect to demographic, radiographic, and surgical characteristics.

DISCUSSION

In this large cohort of ASD patients, GBTMs revealed four distinct functional patterns over the recovery period following spine surgery. Two groups of patients displayed deterioration or minimal changes in functional status with persistent moderate to high levels of disability throughout the study follow-up, while the other two groups had marked improvement in general. Notably, there were two groups of

TABLE 1. Comparison of Patients' Demographic and Comorbidities Across Subgroups of Functional Status

	Group 1 (N = 117)	Group 2 (N = 469)	Group 3 (N = 333)	Group 4 (N = 252)	Global *P* Value*	*P* Value (Grp 2 *vs.* 3)†
Age, yrs, mean (SD)	46.8 (19.5)	60.3 (15.3)	63.3 (11.5)	60.2 (11.1)	<0.001	0.003
Sex, N (%)						
Males	34 (29.3)	128 (28.1)	78 (23.9)	60 (24.3)	0.425	0.188
Females	82 (70.7)	327 (71.9)	248 (76.1)	187 (75.7)		
Prior surgery, N (%)	22 (19.1)	194 (43.7)	179 (55.3)	166 (67.8)	<0.001	0.002
BMI, N (%)						
Underweight/normal	75 (64.1)	170 (37.0)	94 (28.7)	59 (24.0)	<0.001	<0.001
Overweight	31 (26.5)	174 (37.9)	108 (33.0)	83 (33.7)		
Obese	11 (9.4)	115 (25.1)	125 (38.2)	104 (42.3)		
CCI, N (%)						
0	74 (63.2)	146 (31.4)	80 (24.1)	65 (25.9)	<0.001	0.013
1	18 (15.4)	116 (24.9)	73 (22.0)	43 (17.1)		
≥2	25 (21.4)	203 (43.7)	179 (53.9)	143 (57.0)		
ASA, N (%)						
1	26 (24.8)	32 (7.2)	8 (2.5)	2 (0.8)	<0.001	<0.001
2	60 (57.1)	247 (55.6)	142 (43.8)	94 (39.2)		
3	17 (16.2)	160 (36.0)	167 (51.5)	141 (58.8)		
4	2 (1.9)	5 (1.1)	7 (2.2)	3 (1.2)		
SRS-Schwab deformity, N (%)						
N	16 (14.4)	171 (39.5)	138 (44.4)	124 (54.4)	<0.001	0.214
T	12 (10.8)	10 (2.3)	10 (3.2)	7 (3.1)		
L	40 (36.0)	141 (32.6)	102 (32.8)	72 (31.6)		
D	43 (38.7)	111 (25.6)	61 (19.6)	25 (10.9)		
Yrs of spine problem						
<5 yrs	21 (19.3)	92 (22.0)	77 (24.2)	42 (17.8)	0.368	0.561
5–10 yrs	30 (27.5)	108 (25.8)	72 (22.6)	52 (22.0)		
>10 yrs	58 (53.2)	219 (52.3)	169 (53.1)	142 (60.2)		
Leg pain, median (IQR)	0 (0, 4)	5 (1, 7)	6 (3, 8)	7 (4, 8)	<0.001	0.001
Back pain, median (IQR)	5 (2, 7)	7 (5, 8)	8 (7, 9)	9 (8, 10)	<0.001	<0.001
Levels fused≥10	69 (60.5)	178 (39.6)	130 (40.0)	109 (44.5)	<0.001	0.920
LIV (pelvis/sacrum)	58 (50.9)	345 (76.8)	271 (83.4)	220 (89.8)	<0.001	0.026
UIV (≥T10)	29 (25.4)	250 (55.7)	182 (56.0)	132 (53.9)	<0.001	0.929

**The global P value was a comparison of patients' characteristics across four groups.*
†This P value was a pairwise comparison of patients' characteristics between groups 2 and 3.

patients who started with a similar level of disability, but ended up with opposite recovery trajectories, which appears to relate to significant differences in baseline mental health status. Understanding this heterogeneity among patients is a necessary step in characterizing functional recovery and perhaps in identifying risk factors that distinguish outcomes in surgically-treated ASD patients.

In our study, the group of patients presenting with the highest ODI scores before surgery had only limited recovery of functional status, thus remaining with severe disability. This may imply that the timing of surgical treatment should be considered, avoiding disability to a degree where meaningful improvement becomes less likely. Similar results have been observed in a previous study using the same cohort, as Smith *et al*[18] have found that the severity of preoperative disability measured by ODI was a significant predictor of favorable clinical outcomes for ASD patients undergoing surgery. Hence, early surgical intervention may be important in achieving optimal surgical outcomes. This may be explained by increasing patient-reported disability reflecting more complex deformity thus requiring more complicated surgeries, which are associated with greater likelihood of reoperation and postoperative complications.[19–21] However, several studies have reported that among the elderly, patients with worse baseline disability were more likely to have a greater improvement than those with lower baseline disability.[22–25] The underlying assumptions for those analyses were 1) patients come from a single population, 2) a single trajectory adequately characterizes an entire population, and 3) covariates that affect the recovery processes influence each patient in the same way. These assumptions not only limit the typical longitudinal data analysis but also may result in inaccurate estimates of recovery patterns in ASD patients when a single-group trajectory was used to

TABLE 2. Comparison of Preoperative HRQOL and Radiographic Parameters Across Subgroups of Functional Status

	Group 1 (N = 117)	Group 2 (N = 469)	Group 3 (N = 333)	Group 4 (N = 252)	Global *P* Value*	*P* Value (Grp 2 *vs.* 3)†
Baseline ODI	14.6 (10.2)	38.9 (10.8)	48.9 (10.7)	65.6 (11.5)	<0.001	<0.001
Baseline SF36 PCS	46.2 (9.8)	32.4 (7.9)	28.1 (7.7)	24.9 (5.8)	<0.001	<0.001
Baseline SF36 MCS	53.3 (10.8)	48.6 (12.6)	44.1 (12.9)	36.4 (13.9)	<0.001	<0.001
Baseline SRS Total Score	3.6 (0.5)	2.9 (0.5)	2.6 (0.5)	2.2 (0.5)	<0.001	<0.001
Baseline SRS activity	4.2 (0.6)	3.1 (0.7)	2.6 (0.7)	2.0 (0.6)	<0.001	<0.001
Baseline SRS mental	4.1 (0.8)	3.6 (0.8)	3.3 (0.8)	2.9 (1.0)	<0.001	<0.001
Baseline SRS pain	3.6 (0.8)	2.5 (0.7)	2.1 (0.7)	1.7 (0.6)	<0.001	<0.001
Baseline SRS appearance	3.0 (0.8)	2.6 (0.7)	2.3 (0.6)	2.0 (0.7)	<0.001	<0.001
Baseline PT	18.8 (11.2)	23.9 (10.4)	25.3 (10.3)	25.8 (10.7)	<0.001	0.067
Baseline PI	55.1 (13.4)	55.1 (13.2)	55.9 (12.7)	54.0 (19.3)	0.544	0.435
Baseline PI-LL	4.5 (19.3)	15.4 (20.9)	19.2 (20.5)	21.9 (27.7)	<0.001	0.015
Baseline SVA	27.0 (57.7)	58.3 (66.3)	78.0 (73.0)	100.2 (76.1)	<0.001	<0.001
Baseline TPA	15.2 (12.2)	22.2 (12.5)	25.1 (12.6)	27.4 (13.6)	<0.001	0.002
Baseline UT Cobb	24.1 (12.4)	19.1 (11.6)	17.9 (11.1)	15.9 (10.0)	<0.001	0.334
Baseline TH Cobb	38.5 (20.6)	29.4 (20.3)	27.3 (20.1)	22.7 (16.6)	<0.001	0.297
Baseline TL Cobb	50.2 (23.9)	31.4 (21.9)	30.5 (22.1)	26.0 (20.0)	<0.001	0.623
Baseline LL Cobb	24.4 (14.7)	26.4 (15.2)	23.4 (13.1)	24.1 (14.1)	0.088	0.017
Baseline C7PL	32.9 (30.4)	31.7 (28.3)	34.9 (34.1)	39.2 (37.0)	0.044	0.171

*The global P value was a comparison of patients' characteristics across four groups.

†This P value was a pairwise comparison of patients' characteristics between groups 2 and 3.

LL Cobb indicates lumbar coronal Cobb angle; SF36 MCS, Short-Form Mental Component Score; SF36 PCS, Short-Form Physical Component Score; TH Cobb, thoracic coronal Cobb angle; TL Cobb, thoraco-lumbar coronal Cobb angle; UT Cobb, upper thoracic coronal Cobb angle.

TABLE 3. Comparison of 1-year Postop HRQOL and Radiographic Parameters Across Subgroups of Functional Status

	Group 1 (N = 117)	Group 2 (N = 469)	Group 3 (N = 333)	Group 4 (N = 252)	Global *P* Value*	*P* Value (Grp 2 *vs.* 3)†
1 yr ODI	6.0 (5.7)	14.5 (10.0)	35.2 (10.0)	55.3 (11.6)	<0.001	<0.001
1 yr SF36 PCS	51.9 (5.7)	45.4 (7.6)	35.8 (8.4)	29.6 (7.4)	<0.001	<0.001
1 yr SF36 MCS	56.9 (6.5)	55.0 (9.4)	49.0 (12.2)	42.2 (13.9)	<0.001	<0.001
1 yr SRS Total Score	4.4 (0.4)	4.1 (0.5)	3.4 (0.6)	2.8 (0.6)	<0.001	<0.001
1 yr SRS Activity	4.5 (0.5)	4.0 (0.6)	3.2 (0.7)	2.5 (0.6)	<0.001	<0.001
1 yr SRS Mental	4.4 (0.6)	4.2 (0.6)	3.7 (0.8)	3.2 (0.9)	<0.001	<0.001
1 yr SRS Pain	4.3 (0.5)	4.0 (0.7)	3.1 (0.8)	2.3 (0.7)	<0.001	<0.001
1 yr SRS Appearance	4.4 (0.6)	4.1 (0.7)	3.4 (0.7)	2.9 (0.8)	<0.001	<0.001
1 yr SRS Satis	4.7 (0.5)	4.5 (0.7)	4.1 (0.9)	3.8 (1.1)	<0.001	<0.001
1 yr PT	17.6 (9.9)	20.8 (9.9)	22.5 (9.1)	21.6 (10.4)	0.002	0.045
1 yr PI-LL	−0.7 (12.2)	1.9 (15.1)	4.3 (14.1)	3.9 (19.8)	0.052	0.072
1 yr SVA	2.7 (35.2)	19.6 (51.7)	32.8 (55.6)	47.2 (51.9)	<0.001	0.007
1 yr TPA	12.2 (9.1)	16.1 (10.9)	18.6 (10.1)	19.2 (10.5)	<0.001	0.010
1 yr UT Cobb	16.7 (8.7)	14.8 (9.2)	13.1 (8.3)	11.8 (9.2)	0.021	0.175
1 yr TH Cobb	20.6 (13.6)	17.7 (14.3)	17.4 (16.6)	15.1 (14.8)	0.339	0.879
1 yr TL Cobb	23.5 (18.7)	17.5 (14.0)	15.8 (13.8)	15 (18.0)	0.002	0.244
1 yr LL Cobb	10.6 (10.5)	13.2 (11.3)	12.3 (10.3)	11.8 (9.3)	0.341	0.448
1 yr C7PL	22.2 (17.5)	25.3 (19.6)	29.4 (22.7)	28.7 (25.0)	0.025	0.033

*The global P value was a comparison of patients' characteristics across four groups.

†This P value was a pairwise comparison of patients' characteristics between groups 2 and 3.

LL Cobb indicates lumbar coronal Cobb angle; SF36 MCS, Short-Form Mental Component Score; SF36 PCS, Short-Form Physical Component Score; TH Cobb, thoracic coronal Cobb angle; TL Cobb, thoraco-lumbar coronal Cobb angle; UT Cobb, upper thoracic coronal Cobb angle.

TABLE 4. Comparison of Rate of Patient Reaching a MCID at 1 Year Across Subgroups of Functional Status

	Group 1 (N = 117)	Group 2 (N = 469)	Group 3 (N = 333)	Group 4 (N = 252)	Global P Value*	P Value (Grp 2 vs. 3)†
ODI, N (%)	23 (28.1)	212 (77.4)	99 (43.6)	54 (36.0)	<0.001	<0.001
SF36 PCS	37 (45.7)	215 (82.7)	118 (57.3)	62 (45.6)	<0.001	<0.001
SRS activity	38 (45.2)	214 (78.7)	139 (61.8)	86 (57.7)	<0.001	<0.001
SRS mental	30 (35.7)	137 (50.4)	100 (44.4)	59 (39.6)	0.001	0.003
SRS pain	55 (65.5)	230 (84.6)	141 (62.7)	82 (55.0)	<0.001	<0.001
SRS appearance	70 (83.3)	217 (79.8)	152 (67.6)	87 (58.4)	<0.001	0.005

*The global P value was a comparison of patients' characteristics across four groups.
†This P value was a pairwise comparison of patients' characteristics between groups 2 and 3.
SF36 PCS indicates Short-Form Physical Component Score.

describe a heterogeneous population.[15] In contrast, GBTMs allow identification of latent clusters of patients following similar functional recovery after surgery and therefore to further define the specific groups of patients that truly received significant alleviation of symptoms.

We also observed that younger patients, who primarily had adult idiopathic scoliosis (AIS) with relatively low ODI scores before surgery, tended to have a full recovery over time. The goals of operation among those patients were to relieve pain, prevent progressive deformity, improve appearance, and reduce the risk of other complications, such as spinal stenosis with radiculopathy and muscle fatigue. A systematic review examining the effect of surgery on the quality of life of AIS patients has shown that self-image was the only domain that achieved minimum clinical important difference (MCID) at 2 years following surgery, while surgery had little effect on patient functional limitations and pain intensity.[26] Cosmesis therefore seemed to be the strongest reason for AIS patients to seek surgical treatment. Moreover, since those patients are younger and have better health conditions than ASD patients, they are at reduced risk of experiencing postoperative complications as well as requiring extensive surgeries, which favors an accelerated recovery. However, it is worth noting that ODI scores may not be the ideal measure to capture the recovery process for younger AIS patients as they are less sensitive to functional limitations of daily activities that tend to impact older ASD patients.

Interestingly, our study demonstrated that mental health positively drives the trajectory of recovery in ASD patients, which is consistent with previous findings.[27,28] For example, a systematic review that evaluated the association of preoperative psychological factors and clinical outcomes following lumbar spinal fusion found that higher levels of depression and lower SF-36 Mental Component Scores (MCS) at baseline are the most commonly reported psychological factors that result in unfavorable outcomes.[27] Bakhsheshian *et al*[28] reported that ASD patients with poor mental health had difficulties in obtaining improvements in physical function, as measured by SF-36 physical component summary (PCS) at 2-year follow-up after surgery. In fact, the psychological effect persisted in our data even after controlling for confounding factors, which was not supported by a prospective cohort study that compared clinical outcomes in patients with and without depression at baseline.[29] Future studies are warranted to further understand the causal pathway of psychological effect on functional performance.

TABLE 5. Comparison of 2-year Postop HRQOL Across Subgroups of Functional Status

	Group 1 (N = 117)	Group 2 (N = 469)	Group 3 (N = 333)	Group 4 (N = 252)	Global P Value*	P Value (Grp 2 vs. 3)†
2 yr ODI	3.5 (4.6)	14.7 (10.3)	34.5 (10.4)	55.6 (11.9)	<0.001	<0.001
2 yr SF36 PCS	53.7 (4.7)	45.9 (8.5)	34.7 (7.5)	28.6 (7.1)	<0.001	<0.001
2 yr SF36 MCS	57.1 (5.9)	54.8 (8.9)	48.7 (11.8)	41.1 (14.7)	<0.001	<0.001
2 yr SRS total score	4.5 (0.3)	4.1 (0.5)	3.4 (0.6)	2.8 (0.6)	<0.001	<0.001
2 yr SRS activity	4.6 (0.3)	4.1 (0.6)	3.2 (0.7)	2.4 (0.6)	<0.001	<0.001
2 yr SRS mental	4.5 (0.5)	4.2 (0.7)	3.6 (0.8)	3.3 (1.0)	<0.001	<0.001
2 yr SRS pain	4.5 (0.5)	4.0 (0.7)	3.0 (0.9)	2.4 (0.9)	<0.001	<0.001
2 yr SRS appearance	4.4 (0.6)	4.1 (0.7)	3.3 (0.7)	2.8 (0.8)	<0.001	<0.001
2 yr SRS satisfactory	4.7 (0.6)	4.5 (0.7)	3.9 (1.0)	3.6 (1.1)	<0.001	<0.001

*The global P value was a comparison of patients' characteristics across four groups.
†This P value was a pairwise comparison of patients' characteristics between groups 2 and 3.
SF36 MCS indicates Short-Form Mental Component Score; SF36 PCS, Short-Form Physical Component Score.

The primary strength of the current study is the application of GBTMs in ASD patients, which allows identification of specific patterns of recovery over time and the characteristics associated with distinct trajectories. Limitations of the current study include the small sample size and limited number of follow-up time points which may affect estimated trajectory group shape and classes. Future studies with large sample size and longer follow-up are needed to replicate our findings. Moreover, other potential risk factors, such as length of hospital stay, may also affect the functional status, which should be taken into account in future studies.

CONCLUSION

On the basis of the findings in this study, group-based trajectory models may facilitate research on improving treatment effectiveness and adopting patient-centered care in ASD patients. GBTMs can identify patients with distinct patterns of functional recovery so that investigators can target different pre- and postoperative interventions to patients with different recovery experiences. Our results also demonstrate the potential importance of early surgical treatment to prevent the progression of deformity and therefore optimize the ultimate clinical outcomes. Finally, mental health is crucial in setting correct expectations for outcomes and helping surgical decision making.

➢ Key Points

- Classifying long-term recovery following ASD surgery is crucial for setting and analyzing treatment goals.
- The GBTM allows us to delineate and visualize distinct developmental trajectories of functional status over time and therefore identify patient characteristics associated with the observed functional patterns.
- Patients with moderate or low disability are more likely to achieve better functional outcomes after surgery. Particularly, greatest improvement appears to occur in moderately disabled patients with good mental health.
- Early surgical interventions should be considered to prevent progression of deformity and symptoms, and thus to optimize the potential for favorable outcomes.

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