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ASD

Surgical invasiveness, reoperation, and preoperative depression are predictive of super-utilization in adult spinal deformity surgery

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Abstract
Purpose A subset of adult spinal deformity (ASD) patients undergoing corrective surgery receive a disproportionate level of medical resources and incur greater costs. We examined the characteristics of such super-utilizers of health care resources among ASD patients.

Methods This prospective, multicenter study analyzed data from ASD patients with > 4 levels of spinal fusion and a minimum 2-year follow-up. Index and total episode-of-care (EOC) costs in 2022 US dollars were calculated using average itemized direct costs obtained from administrative hospital records. Patients with total 2-year EOC cost > 90th percentile were considered super-utilizers, the characteristics of which we identified through a multivariate generalized logistic model.

Results Of 1299 eligible patients, mean age was 60 years, 73% were female and 92% were Caucasian. Super-utilizers were older (+2.1 years; $p = 0.012$), had greater depression (34.2 vs 25.7%; $p = 0.03$), increased frailty ($p = 0.009$) comorbidities ($p = 0.005$), higher reoperation rates (54.4 vs 15.0%; $p < 0.001$), hospital length of stay (+ 3 days; $p < 0.0001$), higher surgical invasiveness (+28.6; $p < 0.001$), more vertebrae fused (+ 3; $p < 0.0001$); interbody fusions (80 vs 55%; $p < 0.0001$), bone morphogenetic protein (BMP) use (87.3 vs 69.4%; $p = 0.0001$), operative time (+91 min; $p < 0.0001$), and blood loss (+620 mL; $p < 0.0001$) compared to other ASD patients. Index cost was 65% ($p < 0.0001$), and cost/quality-adjusted life-year was three times higher among super-utilizers.

Conclusion ASD patients with depression who undergo more complex or revision spinal surgical procedures are more likely to be super-utilizers. Identifying likely super-utilizers within the ASD population may enable targeted interventions and preoperative planning to reduce unnecessary costs, while improving patient outcomes.

Keywords Adult spinal deformity · Spinal diseases · Health care costs · Cost–benefit analysis · Quality of life · Adult

Introduction

In 2019, total inflation-adjusted U.S. healthcare expenditures were 30% higher than in 2009 ($3,453 billion compared to $2,658 billion) [1]. Adult spinal disorder (ASD) represents a significant burden on our healthcare system [2]. The annual nationwide expenditure for spinal care is estimated at over $86 billion [3], with an average cost for ASD estimated at $103,143 [4]. Individuals with ASD have better quality of life (QOL) following surgery compared to nonoperative treatment management [2, 5, 6]. Studies investigating factors that impact ASD treatment costs have found that patient age, surgical invasiveness, hospital stay, and operating room costs account for 80% of the total cost [7, 8]. Healthcare costs are unevenly distributed across patient populations, and analyses of health care expenditures show that 5% of the population accounted for more than half (51.2%) of the total health care expenses in 2021 [9–11]. Individuals who use a disproportionately large share of healthcare resources are referred to as super-utilizers [12].

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Knowledge of the factors contributing to disproportionate resource use will inform strategies to lower costs and improve the overall value of ASD surgery for all such patients. Identifying patients with the highest risk of increased costs enables healthcare providers to customize treatment plans to reduce expenses and enhance outcomes. As healthcare costs continue to rise, it is useful to know more about the clinical and demographic profile of super-utilizers to enhance the sustainability and cost-effectiveness of ASD surgical procedures. This study aims to identify factors that drive disproportionate resource utilization among ASD super-utilizers to increase treatment value among this population while optimizing patient care.

Methods

Data source

Data for this study were obtained from a prospective, multicenter registry of ASD patients surgically treated from 2008 to 2020 at one of 23 participating U.S. research sites. The research was authorized by the Institutional Review Board, and each site followed an approved protocol. Participants provided written consent for their participation in the study.

The study's inclusion requirements were patient age ≥ 18 years and at least one of the following criteria: scoliosis $^{>}20^{0}$, sagittal vertical axis $^{>}5$ cm, and pelvic tilt $^{>}25^{0}$. Exclusion criteria included spinal deformities associated with acute trauma or with autoimmune, neoplastic, neuromuscular, syndromic, and/or infectious disorders.

Study population

All eligible patients undergoing adult spinal deformity surgery at participating centers during the study period were included in the database. Alongside the registry database inclusion criteria, this study included patients who had undergone surgical treatment for ASD, who had four or more fusion levels and a 2-year minimum follow-up.

Data collection

Demographic, surgical, and radiographic data were evaluated. Baseline patient demographic data included age, sex, body mass index, Charlson comorbidity index (CCI), frailty score, and depression status. Surgical characteristics included the number of spinal levels fused, surgical approach, performance of 3-column osteotomy, use of interbody fusion, use of bone morphogenetic protein (BMP), ASD surgical invasiveness index, reoperation rate, operative time, estimated blood loss, and hospital length of stay. Patients were assigned to upper thoracic or thoracolumbar groups based on whether the upper instrumented vertebrae were at T1–T5 or T9–Iliac levels, respectively. Radiographic parameters, including Cobb angel and SRS-Schwab sagittal modifiers, were evaluated using 3 parameters: pelvic incidence-lumbar lordosis mismatch, pelvic tilt, and sagittal vertical axis [13].

Preoperative and 2-year post-procedure patient-reported outcome scores for the Oswestry Disability Index and Scoliosis Research Society−22 questionnaire [14] were recorded.

The index and total episode-of-care (EOC) costs for 2022 were calculated using average itemized direct costs from administrative hospital records for all inpatient EOC events at participating institutions. These costs were adjusted for an annual inflation rate of 3%. The total cost included surgical expenses, hospitalization, implants, laboratory tests, physical therapy, medications, and any additional surgical procedures. Surgical and hospitalization costs covered the duration of the hospital stay, OR time, and surgical intensive care unit stay. Implant costs included those for screws, hooks, wires, cement, rods, and interbody devices. BMP costs were based on the average cost of the kits used (small, 4.2 mg; medium, 8.4 mg; large, 12.0 mg). Additional costs, such as radiological imaging, inpatient therapy (physical, occupational, and speech), phlebotomy services (packed red blood cells, fresh frozen plasma, and blood type), laboratory expenses, and pharmacy costs, were included in the overall cost analysis. The average dollar cost per unit use was calculated and mapped to determine the total cost. Revision surgical costs were calculated using the same cost variables and added to the index costs to reflect the total direct inpatient EOC costs.

For institutions lacking data of the total direct inpatient EOC costs, the totals were derived by summing individual cost variable estimates based on resource utilization, as shown in Fig. 1 [15]. This approach has been used to account for institutions without total direct inpatient EOC costs [15]. Internal validation was conducted by comparing the estimated costs with the reported total direct inpatient EOC costs in institutions that did not provide itemized costs but only reported the total direct inpatient EOC costs.

Patients whose EOC costs over a 2-year period exceeded the 90th percentile were classified as super-utilizers [11, 12]. This means that their healthcare expenses were higher than those of 90% of other patients treated within the same timeframe.

Health-related quality-of-life assessment

The health state or health state utility was derived from the patient-reported SF-36 survey scores, based on six

Cost of OR time x OR time
+ cost of hospital stays x duration of hospital stay
+ cost of SICU stays x duration of SICU stay
+ pharmacy costs x number of medications used
+ radiology costs x number of imaging modalities ordered
+ therapy costs x type of therapy ordered.
+ phlebotomy costs x number of blood products used
+ laboratory costs x number of labs ordered
+ cost per pedicle screws x number of pedicle screws used
+ cost per hook x number of hooks used
+ cost per wire x number of wires used
+ cost per rod x number of rods used
+ cost of cement x amounts of cement used
+ cost of inter body device x number of inter body devices used
+ cost of BMP kit (by size) x number of kits used (by size)
+ revision cost (if applicable)

Fig. 1 A model for resource utilization based on individual cost estimates

dimensions: physical functioning, role limitation, social functioning, pain, mental health, and vitality [16]. Each item has 4–6 levels, giving 18,000 possible health states. Scores are based on standard gamble. Quality-adjusted life-years (QALYs) were calculated to assess how much the patient's QOL improved because of ASD surgery. Cost per QALY was calculated using direct costs to provide a micro-costing perspective that allows for more granular cost analysis. Although Medicare allowable rates, calculated using Medicare Severity Diagnosis-Related Groups (MS-DRGs), are traditionally used to provide a broader, societal perspective on cost estimation, Gum et al. [17] found that Medicare allowable rates underestimate the cost of ASD surgery by 17%. Using direct costs instead of MS-DRGs in ASD cost-effectiveness analyses better reflects the significant cost variations due to differences in technique, instrumentation, and use of biologics at the hospital level [15].

Statistical methods

Analyses comparing super-utilizers and other ASD patients were performed using SAS analytical software. Group means were compared by performing a t test or the Mann–Whitney *U* test. Categorical variables were compared using Chi-squared or Fisher's exact test. A multivariate logistic regression model identified the most significant predictors of a patient being a super-utilizer. Significance was set at $p > 0.05$.

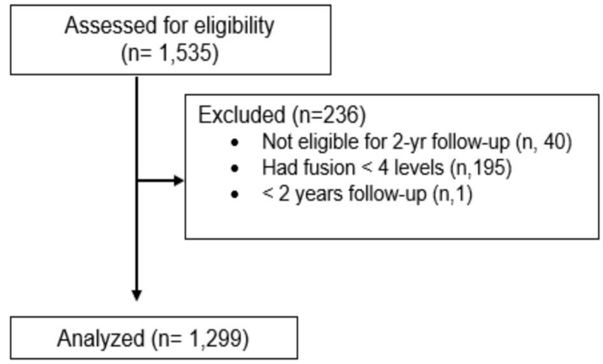

Fig. 2 Flowchart of patients and reasons for exclusion from the study

Results

Patient characteristics

The research cohort comprised 1299 patients diagnosed with ASD who had > 4 spinal fusion levels and 2 years of follow-up data (Fig. 2). The mean patient age was 60 years ± 14.3; the cohort was 73% female and 92% Caucasian. The mean CCI for the cohort was 1.8 ± 1.7, and the frailty index score was 3.5 ± 1.5. At baseline, the super-utilizers were older by 2.1 years, had more comorbidities (mean CCI score of 1.8 vs 2.2; $p < 0.01$), reported elevated frailty scores (3.4 vs 3.8; $p < 0.01$), and had a higher prevalence of depression (25.7 vs 34.2%; $p < 0.03$) (Table 1).

Surgical and radiographic characteristics

Super-utilizers had a mean of 14.4 ± 3.6 spinal levels fused, compared to 11.1 ± 3.3 levels ($p < 0.001$) among the other patients, and 72.9% of super-utilizers had undergone proximal thoracic fusion compared to 36.8% of the other patients. Overall, 59.7% of super-utilizers had a decompression performed and 87.3% of their surgeries used BMP, which was significantly higher ($p < 0.05$) compared to that for the other patients. Super-utilizers had higher ASD surgical invasiveness scores (118.8 vs 90.2, $p < 0.0001$) with increased operating room time, estimated blood loss, length of stay, and number of reoperations compared to the other patients (Table 1). At baseline, the sacral slope, L1 to S1 lordosis, and Cobb angel were the only significant radiographic parameters that varied among the groups.

In the adjusted model, significant factors identified as elevating the odds for being a super-utilizer included depression, use of spinal interbody fusion, BMP use, surgical invasiveness, greater operative time, blood loss, hospital length of stay, and reoperations (all $p < 0.01$) (Table 2). Patients with depression [odds ratio: 2.13, (1.16–3.93),

Table 1 Comparison of baseline characteristics, surgical data, and preoperative radiographic parameters of ASD patients

Characteristic	Super-utilizers ($N=149$)	Other patients ($N=1150$)	*p* value*
Demographics			
Age (mean, *sd*)	62.5 (10.8)	60.4 (14.6)	**< 0.012**
Female (*n*, %)	111 (75.0%)	839 (73.3%)	0.655
BMI (mean, *sd*)	28.6 (5.7)	27.9 (6.0)	0.238
CCI (mean, *sd*)	2.2 (1.9)	1.8 (1.7)	**0.005**
Frailty (mean, *sd*)	3.8 (1.6)	3.4 (1.5)	**0.009**
Depression (*n*, %)	51 (34.2%)	296 (25.7%)	**0.03**
Surgical			
Levels fused (mean, *sd*)	14.38 (3.6)	11.1(3.3)	**< .0001**
Approach			**0.0003**
Posterior only (*n*, %)	81 (54.4%)	795 (69.1%)	
Combine AP (*n*, %)	68 (45.6%)	355 (30.9%)	
Fusion Type: Thoraco-lumbar fusion-short (*n*, %)	39 (27.1%)	697 (63.3%)	**< .0001**
Proximal thoracic fusion-long (*n*, %)	105 (72.9%)	405 (36.8%)	
3-column osteotomy (*n*, %)	37 (24.8%)	216 (18.8%)	0.08
Interbody fusion (*n*, %)	119 (79.9%)	633 (55.0%)	**< 0.0001**
Decompression (*n*, %)	89 (59.7%)	562 (48.9%)	**0.0126**
Bone morphogenetic protein-2 use (*n*, %)	130 (87.3%)	798 (69.4%)	**< 0.0001**
Surgical invasiveness score (mean, *sd*)	118.8 (37.2)	90.2 (33.1)	**< .0001**
OR time (min) (mean, *sd*)	456.6 (142.7)	364.9 (128.0)	**< .0001**
EBL (L) (mean, *sd*)	2.1 (1.8)	1.4 (1.4)	**< .0001**
Reoperations (*n*, %)	81 (54.4%)	173 (15.0%)	**< 0.0001**
LOS (mean, *sd*)	11 (7.4)	8(4.8)	**< .0001**
Baseline radiologic measures (mean, sd)			
Sacral slope	28.1 (10.5)	31.4 (12.2)	**0.0004**
Pelvic tilt	26.1 (11.1)	24.7 (10.8)	0.132
Pelvic incidence	54.2 (12.4)	56.2 (12.9)	0.0804
PI-LL	20.7 (23.0)	18.0 (21.7)	0.1519
L1 to S1 lordosis	33.5 (22.1)	38.1 (21.9)	**0.0149**
C7-S1 SVA	79.7 (77.1)	71.6 (73.6)	0.2123
Max Cobb Angel	43.7 (21.8)	37.7 (20.5)	**0.0010**

Sd standard deviation, *BMI* body mass index, *CCI* Charlson comorbidity index, *AP* anterior–posterior, *OR* operative, *EBL* estimated blood loss, *LOS* length of stay, *PI-LL* pelvic incidence-lumbar lordosis, *SVA* sagittal vertical axis

*Significant values shown in boldface

$p<0.015$] were more likely to be super-utilizers compared to those without depression (Fig. 3). Use of spinal interbody fusion [odds ratio: 4.17 (2.21–7.86), $p<0.0001$], BMP use [odds ratio: 3.25 (1.57–6.74), $p<0.001$], and reoperations significantly had a strong positive effect [odds ratio: 17.38 (9.65–31.3), $p<0.0001$].

Cost analysis

Cost analysis showed that the index surgery cost was significantly higher among super-utilizers compared to other patients (\$94,363.4 ± 47,398.5 for super-utilizers vs \$57,115.5 ± 14,199.5 for other patients; $p<0.01$). The cost for revision surgery was \$16,393 higher among super-utilizers compared to other patients, and the total direct cost was \$54,541 higher among super-utilizers (Table 3).

There was no significant difference in baseline QALY between the two groups (Table 3). The mean 2-year QALY was significantly higher among the other patients compared to that of the super-utilizers ($p<0.01$) and the cumulative QALY gain was more than double among other patients compared to that among super-utilizers (0.2 vs 0.1; $p=0.001$). Cost per QALY gain was higher among super-utilizers compared to other patients (1,641,751 vs. 402,147).

Table 2 Multivariate analysis results or significant predictors for being super-utilizers

Characteristic	Odds ratio (95% confidence interval)	*p* value*
Age	1.00 (0.98–1.03)	0.7843
Charlson comorbidity index	1.03 (0.87–1.22)	0.7267
Frailty	0.92 (0.74–1.13)	0.4182
Had depression	**2.13 (1.16–3.93)**	**0.015**
Number of levels fused	1.19 (0.99–1.44)	0.0662
Approach	1.80 (0.91–3.56)	0.0909
Type of fusion, short vs long	0.72 (0.19–2.80)	0.64
Interbody fusion	**4.17 (2.21–7.86)**	**<.0001**
Decompression	1.03 (0.59–1.80)	0.9148
Bone morphogenetic protein use	**3.25 (1.57–6.74)**	**0.0015**
Invasiveness	**1.01 (1.00–1.02)**	**0.0273**
Reoperation	**17.38 (9.65–31.30)**	**<.0001**
Operative time	**1.00 (1.00–1.01)**	**0.0171**
Estimated blood loss	**1.42 (1.02–1.98)**	**0.0404**
Length of stay	**1.08 (1.04–1.13)**	**<.0001**
Sacral slope	0.98 (0.95–1.01)	0.2325
L1 to S1 lordosis	1.01 (0.99–1.03)	0.6193
Max Cobb angel	1.01 (0.99–1.02)	0.4146

*Significant values are shown in boldface

Health-related quality-of-life scores

Baseline scores were similar for the Oswestry Disability Index, and across various domains of the Scoliosis Research Society-22 questionnaire ($p > 0.05$). Over 2 years, super-utilizers had statically significant lower Oswestry Disability Index scores, as well as total Scoliosis Research Society-22 questionnaire scores compared to those of other ASD patients (Table 4).

Discussion

A large portion of healthcare resources are disproportionately distributed across the U.S. population, including among adults with spinal deformities. This study identified key elements that contribute to ASD patients becoming super-utilizers. The invasiveness of surgical procedures, operative time, blood loss, use of BMP, and length of hospital stay are significant drivers of super-utilization of medical resources. For individuals in our study population, healthcare costs among super-utilizers for the index surgery was $37,248 more than that for the other patients; and the cost of revision surgery was $16,393 more for super-utilizers than for the other patients. The cost per QALY gain was 3 times higher among super-utilizers compared to other patients. To our knowledge, this is the first study to examine the drivers of super-utilizers among ASD patients and to compare the total direct cost and QALY gains.

Data from the Agency for Healthcare Research and Quality's MEPS-HC 2024 illustrate the distribution of healthcare spending among the U.S. civilian noninstitutionalized population. These data show that 78% of super-utilizers had at least 1 comorbid condition [9]. In the current study, super-utilizers had a mean CCI score of 2.19 compared to 1.77 for other ASD patients. Comorbid conditions are frequently seen in individuals who require expensive treatments, such as additional surgeries or hospital stays related to these conditions, which greatly increase the overall medical costs. A study investigating the factors influencing direct costs for single-level lumbar fusion revealed that comorbidities were responsible for a significant portion of the most expensive care episodes, leading to extreme outliers in both length of stay and pharmacy costs [18]. Passias et al. [19] assessed elements that influenced long-term cost-effectiveness and reported that a lower comorbidity burden was highly associated with 5-year cost-effectiveness. However, our study did not find the CCI score to be a significant predictor in the adjusted model after controlling for patient factors, but surgical invasiveness and other surgical factors were significant predictors. A study found that the CCI score was not significantly linked to cost for commercially insured patients after accounting for patient factors [20].

Data from 2012 reported by the Agency for Healthcare Research and Quality showed that the mean length of stay ranged between 5.9 and 6.3 days among super-utilizers compared to 3.6–5.6 days for the other ASD patients [21]. Our study estimated an average length of stay of 8 days among other ASD patients and 11 days among super-utilizers. Our findings are comparable to those from another study that reported an average length of stay of 6.5 (+3.2 days) overall for the ASD patient sample [22]. The difference in length of stay between ASD patients and other average super-utilizers could be due to the fact that ASD surgeries are invasive, often requiring additional hospital stays and resources that further compound the costs. For patients with Medicare and commercial health insurance, a greater length of stay significantly increases the cost [20]. This offers an opportunity for cost savings, where clinical care pathways that help reduce estimated blood loss and operating room time, which are some of the drivers of length of stay, could be expected to decrease the patient's length of stay [22].

Our analysis indicates that the use of BMP was three times more likely to occur in super-utilizers compared to other ASD patients. This finding corroborates another study's report that BMP use was a significant cost driver in spinal surgery [20]. An additional study associated BMP use with greater total costs, independent of fusion type,

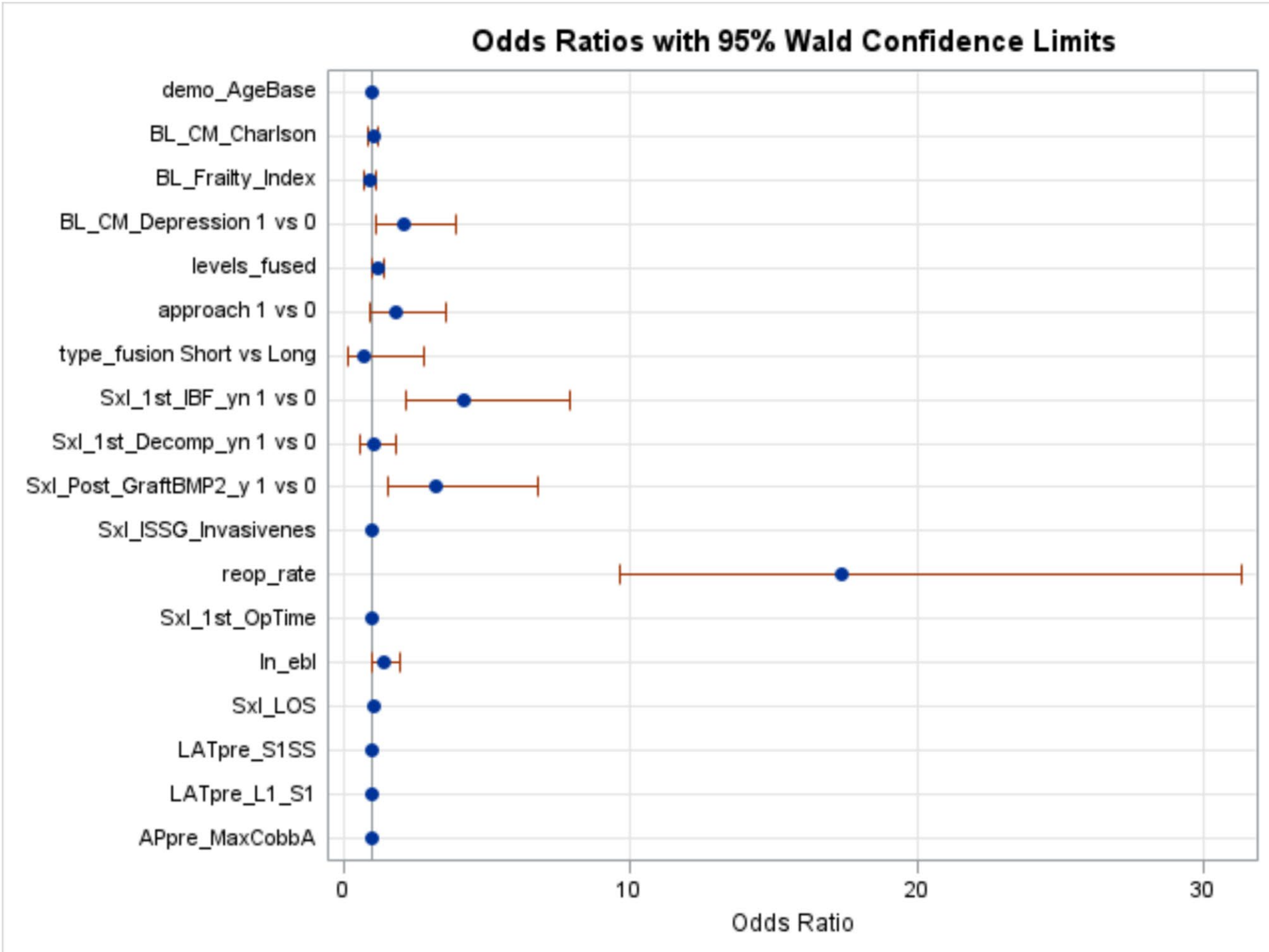

Fig. 3 Odds ratios indicating predictors for being super-utilizers

Table 3 Episode-of-care costs and quality-adjusted life-years of ASD patients

Characteristic	Super-utilizers mean ± standard deviation	Non-super-utilizers mean ± standard deviation	*p* value*
Cost, USD			
Index EOC	94,363.4 ± 47,398.5	57,115.5 ± 14,199.5	**< .0001**
Revision EOC	37,708.4 ± 21,814.7	21,315.1 ± 7023.8	**< .0001**
Total EOC	114,862.6 ± 43,611.2	60,322.0 ± 15,307.0	**< .0001**
QALY			
Baseline QALY	0.7 ± 0.13	0.6 ± 0.11	0.798
2-yr QALY	0.6 ± 0.13	0.63 ± 0.13	**0.005**
Cumulative QALY gain	0.1 ± 0.21	0.2 ± 0.21	**0.001**
Cost/QALY gain, USD	1,641,751.4	402,146.7	NA

EOC episode of care, *QALY* quality-adjusted life-year, *USD* United States dollar

*Significant values are shown in boldface

after multivariate risk adjustment ($p < 0.0001$); however, reimbursement did not increase among the Medicare-insured population [23].

Overall, among other ASD patients, the index surgery cost is $57,115; whereas the index surgery cost is $94,363 among super-utilizers. Passias et al. [24] found that the potential

Table 4 Comparison of patient-reported metrics at baseline and 2 years postoperatively among ASD patients

PROMs	Super-utilizers (*N* = 149)	Other patients (*N* = 1150)	*p* value*
Oswestry disability index			
Base	47.9 ± 18.0	45.1 ± 17.7	0.072
2-yr	34.3 ± 21.8	26.6 ± 20.0	**< 0.0001**
Delta	-13.8 ± 18.5	-17.2 ± 18.2	**0.047**
SRS-22 pain			
Base	2.3 ± 0.8	2.4 ± 0.8	0.167
2-yr	3.2 ± 1.1	3.5 ± 1.1	**0.001**
Delta	0.9 ± 1.0	1.1 ± 1.0	**0.023**
SRS-22 activity			
Baseline	2.7 ± 0.9	2.8 ± 0.9	0.09
2-yr	3.2 ± 1.0	3.6 ± 1.0	**< 0.0001**
Delta	0.5 ± 0.8	0.7 ± 0.9	**0.002**
SRS-22 appearance			
Base	2.3 ± 0.7	2.4 ± 0.8	0.10
2-yr	3.4 ± 0.9	3.6 ± 1.0	**0.02**
Delta	1.10 ± 1.0	1.2 ± 1.0	0.29
SRS-22 mental			
Base	3.3 ± 0.9	3.4 ± 0.9	0.48
2-yr	3.7 ± 0.8	3.9 ± 0.9	0.14
Delta	0.4 ± 0.8	0.4 ± 0.8	0.45
SRS-22 satisfaction			
Base	2.8 ± 1.1	2.7 ± 1.1	0.22
2-yr	3.9 ± 1.1	4.2 ± 1.0	**0.004**
Delta	1.0 ± 1.4	1.4 ± 1.4	**0.002**
SRS-22 total			
Base	2.7 ± 0.6	2.7 ± 0.6	0.14
2-yr	3.4 ± 0.8	3.7 ± 0.8	**0.0004**
Delta	0.7 ± 0.7	0.9 ± 0.7	**0.008**

PRoMs patient-reported outcome measures, *SRS-22* Scoliosis research society−22 questionnaire

*Significant values are shown in boldface

cost of ASD surgery ranged from $57,607 to $116,313, which is comparable to findings from our current study. These increased expenditure among super-utilizers might be partially attributed to more complex surgeries that require longer operative times and increased length of stay [10], surgical invasiveness [9], or when patients experience higher blood loss, all of which can rapidly escalate costs. A recent study concluded that 80% of the overall cost is incurred in the operating theater, with the most important cost categories being implants, other materials, and staff time [7]. Reoperations have been associated with failure to achieve cost-effectiveness, i.e., threshold of $150,000 at 5 years [19, 25, 26]. Revision rates for primary adult spinal fusion surgeries vary from 9 to 45% [25]. Over different follow-up periods, the rates were 44.8% within 0 to 2 years, 29.3% from 2 to 5 years, 12.1% from 5 to 10 years, and 13.8% after 10 years [27]. This study estimated that the additional cost of revision surgery was $37,708 among super-utilizers and $21,315 among the other patients. A retrospective study of the total cost of care attributed to reoperations estimated an additional cost of $59,130 for each reoperation [28]. That study also reported that the total EOC cost was 2.1 times higher in the revision group than the non-revision group ($151,913 vs $71,978, $p < 0.0001$) [26]. The 2-year QALY gain in the surgical revision group was significantly higher than in the non-revision group (0.08 vs 0.03, $p < 0.01$) [28].

Limitations of the database should be considered when interpreting this study's results. First, not all institutions reported actual direct costs, which may introduce some bias into the total cost estimate. To address this, we utilized a previously validated cost estimation model to assess expenditures. Second, the cost estimation was confined to hospital expenses associated with initial and revision surgeries, omitting additional costs such as for outpatient care and treatment cost. Third, the study utilized data from various centers; however, inconsistencies in patient enrollment and duration of data collection restricted the generalizability of the findings to the entire ASD population. Fourth, patients with less than 2 years of follow-up data were excluded from the analyses. Although there may be selection bias, this study evaluated the total cost of care; thus, only those with a minimum of 2 years of follow-up data were included to ensure that we did not underestimate costs.

Conclusion

Individuals diagnosed with ASD who underwent surgical interventions demonstrated notable enhancements in health-related QOL. These results underscore the increased effectiveness and improved QOL experienced by individuals who opted for surgical intervention compared to those who did not. An increasing elderly population and escalating expenses associated with remedial procedures will impose further strains on healthcare resource allocations. To translate our findings into a clinically actionable approach, we propose a preliminary risk-based framework (Fig. 4) for identifying ASD patients at higher risk of becoming healthcare super-utilizers. This framework is informed by key predictors identified in the adjusted multivariate analysis, including preoperative depression, use of interbody fusion, BMP use, surgical invasiveness, operative time, blood loss, reoperations, and prolonged hospital length of stay. Incorporating these factors into preoperative assessment may support targeted optimization strategies, guide surgical planning, and improve value-based care. Thus, future research should strive to develop predictive models for the early detection of high-cost patients and identify targeted interventions to optimize resource utilization

Fig. 4 Risk-based framework to identify super-utilizers in ASD surgery

Risk Domain	Risk Indicators
Psychosocial Health	Clinical diagnosis of depression
Medical conditions	Pre-existing comorbidities, Elevated fraility scores
Surgical factors	Interbody fusion planned; BMP use anticipated; reoperations
Surgical invasiveness	Greater operative time; increased blood loss; increased length of hospital stays

across all patients. Based on these findings, efforts in this area should focus on optimizing depression management and better evaluating the relative risk/benefit of increasing surgical invasiveness and reducing reoperation to optimize cost-effectiveness. Efficiently identifying and carefully evaluating preoperative treatment plans for possible super-utilizers within ASD patients present significant cost-saving opportunities.

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