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DEFORMITY

Costs of Surgery in Adult Spinal Deformity

Do Higher Cost Surgeries Lead to Better Outcomes?

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Study Design. This was a retrospective study.

Objective. To assess the impact of surgical costs on patient-reported outcomes in adult spinal deformity (ASD).

Summary of Background Data. With increased focus on delivering cost-effective health care, interventions with high-resource utilization, such as ASD surgery, have received greater scrutiny.

Materials and Methods. ASD patients aged 18 years and older with BL and 2-year data were included. Surgical costs were calculated using the 2021 average Medicare reimbursement by Current Procedural Terminology code. Costs of complications and reoperations were intentionally excluded. Patients were ranked into tertiles by surgical cost: highest surgical costs (HC) and lowest surgical costs (LC). They were propensity score matched to account for differences in baseline age and deformity. Bivariate logistic regressions assessed odds of achieving outcomes.

Results. Four hundred twenty-one patients met inclusion (60.7 yr, 81.8% female, Charlson Comorbidity Index: 1.6, 27.1 kg/m^2), 139 LC and 127 HC patients. After propensity score matching, 102 patients remained in each cost group with an average reimbursement of LC: \$12,494 *versus* HC: \$29,248. Matched cohorts had similar demographics and baseline health-related quality of life. Matched groups had similar baseline sagittal vertical axis (HC: 59.0 *vs.* LC: 56.7 mm), pelvic incidence and lumbar lordosis (HC: 13.1 *vs.* LC: 13.4°), and pelvic tilt (HC: 25.3 *vs.* LC: 22.4°). Rates of complications were not significantly different between the cost groups. Compared with the LC group, by 2 years, HC patients had higher odds of reaching substantial clinical benefit in Oswestry Disability Index [odds ratio (OR): 2.356 (1.220, 4.551), $P=0.011$], in Scoliosis Research Society-Total [OR: 2.988 (1.515, 5.895), $P=0.002$], and in Numerical Rating Scale Back [OR: 2.739 (1.105, 6.788), $P=0.030$]. Similar findings were appreciated for HC patients in the setting of Schwab deformity outcome criteria.

Conclusions. Although added cost did not guarantee an ideal outcome, HC patients experienced superior patient-reported outcomes compared with LC patients. Although cost efficiency remains an important priority for health policy, isolating cost reduction may compromise outcomes and add to future costs of reintervention, particularly with more severe baseline deformity.

Key words: adult spinal deformity (ASD), clinical outcomes, cost analysis, health care system, propensity score, Medicare reimbursement

Level of Evidence. 3.

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Enthusiasm for adult spinal deformity (ASD) surgery has grown over the last two decades.[1] At the same time, these procedures are resource-intensive, expensive and carry a high complication profile.[2] The potential for complications also extends well beyond the initial postoperative period, and mechanical failure and consequent need for revision frequently occur several years following the index intervention. From a health policy perspective, the high cost associated with ASD surgery has been a target of increased scrutiny. General projections of health expenditures estimate that health care will reach 19.7% of the US gross domestic product by 2028, with Medicare experiencing the fastest growth in spending of major payers.[3] Given that the prevalence of ASD has been estimated as high as 68% for those over age 60, it is unsurprising that costly interventions occurring more often in elderly patients are of significant interest to policymakers.[4] Although more invasive surgical interventions may be more expensive at baseline, they may also obviate the need for more expensive care in the years following the index surgery.

At present, it remains unclear whether more aggressive and expensive procedures have the capacity to pay longer term dividends in terms of superior patient outcomes and lower likelihood of adverse events and revisions. Comparisons are frequently inhibited by a lack of sufficient follow-up, as well as confounding due to selection and indication bias. In an effort to address these questions in a more comprehensive fashion, we used a large, prospectively collected, spine surgical registry with extensive follow-up to evaluate differences in outcomes between higher cost and lower cost deformity procedures. This surgical registry has been utilized previously to address health policy questions in the setting of ASD surgery. We used propensity score matching (PSM) as a causal inference test to address issues of confounding by indication at baseline. We hypothesized that following matched analysis, higher cost ASD surgeries would outperform lower cost interventions in terms of both patient-reported outcomes and deformity correction.

MATERIALS AND METHODS

Study Design and Setting

This study is a retrospective analysis of patients prospectively enrolled in a single-center ASD database. Internal Review Board approval was obtained before study initiation, and informed consent was given by each included patient before enrollment in the registry. The means by which patients are deemed eligible for inclusion in this registry and the processes for data collection have been described in previous work. For inclusion in the present investigation, operative ASD patients in the registry had to have complete baseline and 2-year radiographic and health-related quality of life (HRQL) data.

Data Collection and Radiographic Parameters

Demographic data collected consisted of patient age, sex, body mass index (BMI), and Charlson Comorbidity Index (CCI). Surgical parameters included: levels fused, length of stay, operative time, decompressions, surgical approach, and osteotomies. HRQL measures collected at baseline and follow-up visits were: Scoliosis Research Society Outcomes Questionnaire (SRS-22), Oswestry Disability Index (ODI), and Numerical Rating Scale (NRS) for back pain. Improvement in outcomes were evaluated utilizing minimal clinical importance difference (MCID) and substantial clinical benefit (SCB) thresholds and based on published values.[5] MCID thresholds were +0.77, −12.8, and −1.2 for SRS-22 Total, ODI, and NRS Back, respectively.[6,7] SCB thresholds were +1.11, −18.8, and −2.5 for ODI, SRS-22 Total, and NRS Back, respectively.[8,9] At baseline and follow-up intervals, full-length free-standing lateral spine radiographs (36-inches cassette) were collected. Using validated software (Surgimap; Nemaris Inc., New York, NY), radiographic images were analyzed according previously published validated and standardized techniques.[10–13] Spinopelvic radiographic parameters measured included pelvic incidence (PI), pelvic tilt (PT), sagittal vertical axis (SVA), and mismatch between pelvic incidence and lumbar lordosis (PI–LL).

Statistical Analysis

Total cost data were based on average Medicare reimbursement by applicable Current Procedural Terminology (CPT) codes obtained from the physician fee schedule at https://www.cms.gov. Costs of complications and reoperations were intentionally excluded from cost calculation. The cohort was then ranked into tertiles by total cost. Patients in the tertile with the highest surgical costs (HC) and lowest surgical costs (LC) were PSM to account for differences in baseline demographics and deformity. After PSM, means comparison tests assessed demographic, surgical, radiographic factors, and HRQL metrics at baseline and 2 years between LC and HC groups. In the PSM cost groups, binary outcomes were analyzed using bivariable logistic regressions and continuous outcomes were analyzed using analysis of covariance, with demographics and baseline deformity included as covariates for all analyses. When assessing HRQL outcomes, baseline for the respective HRQL was included as a covariate and when assessing postoperative alignment, reoperation was included as a covariate. All statistical analyses were performed using SPSS, Version 25 (IBM Corp., Armonk, NY), with statistical significance defined for all tests as P-value <0.05.

RESULTS

Cohort Demographics, Baseline Deformity, and HRQLs

Four hundred twenty-one patients met the initial inclusion criteria, with 139 patients in the LC group and 127 patients in the HC group. After PSM, 204 patients remained in the cohort, with 102 patients in each group. The mean cost of the cohort was \$20,871 ± \$10,274. Patients had a mean age of 60.7 ± 13.9 years, mean CCI of 1.6 ± 1.6, mean BMI of 27.1 ± 5.7 kg/m^2, and mean ASD-frailty index of 0.3 ± 0.2. The cohort was 81.8% female. Radiographically, cohort presented with: PT of 23.9 ± 11.6°, PI–LL of 13.2 ± 19.8°, and SVA of 57.9 ± 62.3 mm. With respect to baseline HRQLs, the mean baseline ODI was 39.9 ± 18.7, mean SRS-22 Total was 2.9 ± 0.7, and mean NRS Back was 6.7 ± 2.4.

Demographics, Baseline Deformity, and HRQLs by Cost Group

The mean cost of the LC group was \$12,494 ± \$8,177 *versus* HC: \$29,248 ± \$1,887. Cost groups had similar baseline age (HC: 60.3 ± 10.9 *vs*. LC: 61.0 ± 16.5 yr), CCI (HC: 1.5 ± 1.6 *vs*. LC: 1.7 ± 1.6), BMI (26.5 ± 5.0 *vs*. 27.6 ± 6.4 kg/m^2), and ASD-frailty index (HC: 0.3 ± 0.2 *vs*. LC: 0.3 ± 0.2) with similar gender composition (HC: 86.1% *vs*. LC: 77.5%), all $P > 0.05$ (Table 1). In addition, baseline deformity was not significantly different between cost

TABLE 1. Demographics of Cost Groups

Demographics	Mean ± SD			P
	Cohort	Low cost	High cost	
N	204	102	102	
Surgical cost (US$)	20,871 ± 10,274	12,494 ± 8,177	29,248 ± 1,887	< 0.001
Age (yr)	60.7 ± 13.9	61.0 ± 16.5	60.3 ± 10.9	>0.05
Sex (% female)	81.8	77.5	86.1	>0.05
BMI (kg/m^2)	27.1 ± 5.7	27.6 ± 6.4	26.5 ± 5.0	>0.05
CCI	1.6 ± 1.6	1.7 ± 1.6	1.5 ± 16	>0.05
ASD-FI	0.3 ± 0.2	0.3 ± 0.2	0.3 ± 0.2	>0.05

ASD-FI indicates adult spinal deformity frailty index; BMI, body mass index; CCI, Charlson Comorbidity Index.

groups (Table 2). Finally, with respect to baseline HRQLs, cost groups had similar baseline ODI (HC: 38.6 ± 18.7 *vs.* LC: 41.1 ± 18.7), SRS-Total (HC: 2.9 ± 0.7 *vs.* LC: 3.0 ± 0.6), and NRS Back (HC: 6.6 ± 2.5 *vs.* LC: 6.8 ± 2.3), all $P > 0.05$.

Surgical Details by Cost Group

Patients in the HC group had significantly higher EBL (1982 ± 1315 *vs.* 856 ± 867 mL, $P < 0.001$), LOS (8 ± 4 *vs.* 6 ± 4 days, $P = 0.002$), and operative times (380 ± 133 *vs.* 306 ± 136 minutes, $P < 0.001$). HC patients had significantly more levels fused (15.7 ± 1.9 *vs.* 6.6 ± 3.3, $P < 0.001$) and higher rates of osteotomy (90.2% *vs.* 34.3%, $P < 0.001$), whereas the LC group had higher rates of interbody fusion (51.0% *vs.* 67.6%, $P = 0.015$). Although HC patients tended to have higher rates of major complications (30.3% *vs.* 20.2%) and reoperations (22.5% *vs.* 19.6%), these differences were not significant, both $P > 0.05$. Furthermore, multivariate logistic regression analysis found no significant differences in odds of major complications or reoperations between cost groups, all P values > 0.05.

Radiographic Outcomes by Cost Group

Multivariable logistic regression analysis found that HC patients had a 3.4× higher odds of achieving "0" SVA Schwab modifier at 1 year [odds ratio (OR): 3.441 (1.725, 6.863), $P < 0.001$] and 5.2× higher odds of achieving "0" SVA Schwab modifier at 2 years [OR: 5.245 (2.507, 10.973), $P < 0.001$].

TABLE 2. Baseline Radiographic Measurements and SRS-Schwab Modifiers Between High-cost and Low-cost Groups

Baseline deformity	Cohort	Low cost	High cost	P
N	204	102	102	
SVA (mm)	57.9 ± 62.3	59.0 ± 63.3	56.7 ± 61.6	>0.05
PI–LL (°)	13.2 ± 19.8	13.4 ± 17.9	13.1 ± 21.6	>0.05
PT (°)	23.9 ± 11.6	22.4 ± 11.4	25.3 ± 11.7	>0.05
SRS-Schwab Modifiers				
SVA (%)				
0	44.9	47.5	42.4	> 0.05
+	28.3	27.3	29.3	> 0.05
++	26.8	25.3	28.3	> 0.05
PI–LL (%)				
0	43.4	43.4	43.4	>0.05
+	19.2	17.2	21.2	>0.05
++	37.4	39.4	35.4	>0.05
PT (%)				
0	37.4	39.4	35.4	>0.05
+	35.9	36.4	35.4	>0.05
++	26.8	24.2	29.3	>0.05

PI–LL indicates pelvic incidence minus lumbar lordosis; PT, pelvic tilt; SRS, Scoliosis Research Society; SVA, sagittal vertical axis.

Similarly, HC patients had a 2.4× higher odds of achieving "0" PI–LL Schwab modifier at 1 year [OR: 2.359 (1.088, 5.115), $P=0.030$] and 2.7× higher odds of achieving "0" PI–LL Schwab modifier at 2 years [OR: 2.714 (1.258, 5.857), $P=0.011$].

Finally, HC patients had a 2.0× higher odds of achieving "0" PT Schwab modifier at 1 year [OR: 1.953 (1.022, 3.733), $P=0.043$] and 2.2× higher odds of achieving "0" PT Schwab modifier at 2 years [OR: 2.238 (1.188, 4.217), $P=0.013$].

HRQL Outcomes by Cost Group

Multivariable logistic regression analysis found that HC patients had a 2.2× higher odds of reaching MCID in ODI at 1 year [OR: 2.181 (1.096, 4.341), $P=0.026$] and by the 2-year time point, HC patients had a 2.3× higher odds of reaching MCID in ODI [OR: 2.314 (1.200, 4.461), $P=0.012$]. Similarly, HC patients had a 2.1× higher odds of reaching SCB in ODI at 1 year [OR: 2.194 (1.106, 4.352), $P=0.025$] and by the 2-year time point, HC patients had a 2.4× higher odds of reaching SCB in ODI [OR: 2.356 (1.220, 4.551), $P=0.011$]. Table 3 illustrates comparison between MCID and SCB in ODI at 1 and 2 years.

With respect to SRS-22 Total, HC patients had a 1.9× higher odds of reaching MCID at 1 year [OR: 1.915 (1.062, 3.453), $P=0.031$], which increased to 2.2× at 2 years [OR: 2.245 (1.250, 4.032), $P=0.007$]. In addition, HC patients had a 2.1× higher odds of reaching SCB in SRS-22 Total at 1 year [OR: 2.117 (1.078, 4.161), $P=0.030$], which increased to a 3.0× higher odds at 2Y [OR: 2.988 (1.515, 5.895), $P=0.002$]. Table 4 shows MCID and SCB using SRS-22 Total at 1 and 2 years.

With respect to NRS Back, there was no difference in odds of reaching MCID at 1 year; however, HC patients had a 2.9× higher odds of reaching MCID in NRS Back at 2 years [OR: 2.929 (1.182, 7.257), $P=0.020$]. Finally, there was no difference in odds of reaching SCB in NRS Back between cost groups at 1 year, yet by 2 years HC patients had a 2.7× higher odds of reaching SCB [OR: 2.739 (1.105, 6.788), $P=0.030$]. Table 5 shows a comparison between the two groups.

TABLE 3. Multivariable Logistic Regression Predicting Highest Surgical Costs *Versus* Lowest Surgical Costs Meeting MCID and SCB in Oswestry Disability Index at 1 and 2 Years

	OR	Lower	Upper	*P*
1 yr				
MCID	2.181	1.096	4.341	0.026
SCB	2.194	1.106	4.352	0.025
2 yr				
MCID	2.314	1.2	4.461	0.012
SCB	2.356	1.22	4.551	0.011

MCID indicates minimal clinically importance difference; OR, odds ratio; SCB, substantial clinical benefit.

TABLE 4. Multivariable Logistic Regression Predicting Highest Surgical Costs *Versus* Lowest Surgical Costs Meeting MCID and SCB in Scoliosis Research Society-Total at 1 and 2 Years

	OR	Lower	Upper	*P*
1 yr				
MCID	1.915	1.062	3.453	0.031
SCB	2.117	1.078	4.161	0.03
2 yr				
MCID	2.245	1.25	4.032	0.007
SCB	2.988	1.515	5.895	0.002

MCID indicates minimal clinically importance difference; OR, odds ratio; SCB, substantial clinical benefit.

Complications by Cost Group

Multivariable logistic regression analysis found that HC patients had a 1.8× higher odds of a major complication [OR: 1.758 (–0.096, 1.410), $P=0.12$] by the 2-year time point as defined by Klineberg *et al.*[14] Similarly, HC patients had a 1.8× higher odds of any complication [OR: 1.769 (–0.106, 2.352), $P=0.194$] by the 2-year time point, although for minor complications HC patients had similar odds as compared with the LC group [OR: 1.054 (–1.220, 2.551), $P=0.883$].

DISCUSSION

Although prior studies have demonstrated wide variation in costs associated with corrective ASD surgery by geographic region and across institutions, this study utilized a single-center database to assess the relationship between surgical costs, deformity correction, and patient-reported outcomes in ASD patients using PSM to address confounding by indication at baseline.

Following matched analysis, HC patients were more likely to have mild SRS-Schwab modifiers at 1-year follow-up. This

TABLE 5. Multivariable Logistic Regression Highest Surgical Costs *Versus* Lowest Surgical Costs Predicting Meeting MCID and SCB in Numerical Rating Scale Back at 2 Years

	OR	Lower	Upper	*P*
MCID	2.929	1.182	7.257	0.02
SCB	2.739	1.105	6.788	0.03

MCID indicates minimal clinically importance difference; OR, odds ratio; SCB, substantial clinical benefit.

phenomenon persisted at 2 years, becoming more pronounced across all modifiers. A similar pattern was found in the HRQL analysis. At 1 year, HC patients had higher odds of achieving minimal clinically important difference and SCB thresholds for ODI and SRS-22 Total. By 2 years, the odds of achieving SCB in ODI and SRS-22 Total were even greater for HC patients. Although odds of reaching MCID and SCB thresholds for NRS Back were similar between cost groups at 1 year, by 2 years, HC diverged from their LC counterparts and was more likely to reach MCID and SCB.

These findings suggest HC procedures not only result in superior deformity correction but also superior durability of this initial correction. Such differences in deformity correction may account for the greater improvement in HRQLs seen in HC patients. This is also important, as inferior outcomes may require ongoing expensive nonoperative care such as repeated injections, pain medication management, and interventions such as pain pumps and spinal cord stimulators. Suboptimal correction may also contribute to mechanical failures that can prompt the need for additional surgery. For higher cost health interventions like ASD surgery, the SCB of an intervention is critical to achieving cost efficiency. As a result, despite higher initial expenditures in our HC group, these costs may be offset by superior patient-reported outcomes coupled with the longevity of deformity correction.

At the same time, our analysis of surgical outcomes found no significant differences between cost groups in terms of major complications or reoperations. Despite durable correction and superior HRQL outcomes seen in the HC group, HC surgeries did not reduce the odds of reoperation within 2 years. This may stem from the fact that clinical drivers, beyond surgical resource utilization and cost, which were balanced across the groups following PSM are greater contributors to the risks of complications and reoperation. Even still, it remains plausible that loss of correction in LC patients could result in higher rates of reoperation beyond our 2-year surveillance window. Thus, longer term studies are necessary to assess whether the durability of correction in HC patients is outweighed by higher rates of delayed reoperation.

Our results warn against the moral hazard of attempting to reduce health care expenditures by inappropriately modifying index surgical interventions that would, otherwise, be necessary to achieve optimal surgical outcomes for ASD patients. Doing so not only would possibly increase the likelihood of inferior postoperative HRQL outcomes following surgery but could also contribute to continued health care expenditures as patients seek to manage the sequelae of a suboptimal surgical intervention. The findings presented here seem to support that the most cost-efficient strategy is the one that results in durable deformity correction and stable improvements in patient-reported outcomes in the years following surgical correction.

We recognize several limitations associated with this work. First, the retrospective nature of the study impairs definitive conclusions, as not all potential sources of bias could be identified and mitigated even in the context of our causal inference approach. Second, only ASD patients with complete follow-up data were included. This could introduce a surveillance bias, although we believe this was mitigated to some degree by the relatively complete follow-up across the eligible population. Although our PSM approach ostensibly mitigates selection and indication bias, there remains potential for expertise bias that could not be addressed given the study design. Finally, although a relatively large series of patients overall, there is the prospect for restricted clinical variation within our subgroups that could impact generalizability of study findings, especially in light of the truncation that occurs in the setting of a propensity matching process.

CONCLUSIONS

Although added cost did not guarantee an ideal outcome in the 204 patients considered in this matched analysis, individuals in the highest tertile for cost generally experienced superior patient-reported outcomes compared with those in the lowest tertile. Although cost efficiency remains an important priority for health policy, isolating cost reduction may compromise outcomes and add to future costs of reintervention, particularly in patients with more severe baseline deformity. Our results endorse the fact that the most cost-efficient strategy for ASD surgery is the one that results in reliable deformity correction and stable improvements in patient-reported outcomes that persist in the long term without further need for additional interventions or procedures.

➢ Key Points

- ❑ We determined added surgical cost did not guarantee ideal outcomes in patients according to PSM analysis.
- ❑ Individuals in the highest tertile for cost generally experienced superior patient-reported outcomes compared with those in the lowest tertile. A focus on cost reduction may compromise patient outcomes and add further costs of reintervention.
- ❑ Our results endorse the fact that the most cost-efficient strategy for ASD surgery is the one that results in reliable deformity correction and stable improvements in patient-reported outcomes that persist in the long term without further need for additional interventions or procedures.

References

1. Pellisé F, Vila-Casademunt A, Ferrer M, et al. Impact on health related quality of life of adult spinal deformity (ASD) compared with other chronic conditions. *Eur Spine J*. 2015;24:3–11.
2. Teles AR, Mattei TA, Righesso O, Falavigna A. Effectiveness of operative and nonoperative care for adult spinal deformity: systematic review of the literature. *Global Spine J*. 2017;7:170–8.
3. Keehan SP, Cuckler GA, Poisal JA, et al. National Health Expenditure Projections, 2019-28: expected rebound in prices drives rising spending growth. *Health Aff (Millwood)*. 2020;39:704–14.

4. Schwab F, Dubey A, Gamez L, et al. Adult scoliosis: prevalence, SF-36, and nutritional parameters in an elderly volunteer population. *Spine (Phila Pa 1976)*. 2005;30:1082–5.
5. Glassman SD, Copay AG, Berven SH, Polly DW, Subach BR, Carreon LY. Defining substantial clinical benefit following lumbar spine arthrodesis. *J Bone Joint Surg Am*. 2008;90:1839–47.
6. Passias PG, Brown AE, Bortz C, et al. International Spine Study Group. A risk-benefit analysis of increasing surgical invasiveness relative to frailty status in adult spinal deformity Surgery. *Spine (Phila Pa 1976)*. 2021;46:1087–96.
7. Crawford CH III, Glassman SD, Bridwell KH, Berven SH, Carreon LY. The minimum clinically important difference in SRS-22R total score, appearance, activity and pain domains after surgical treatment of adult spinal deformity. *Spine (Phila Pa 1976)*. 2015;40:377–81.
8. O'Brien MF, Kuklo TR, Blanke KM, Lenke LG. *Spinal Deformity Study Group Radiographic Measurement Manual*. Medtronic Sofamor Danek; 2005.
9. Rillardon L, Levassor N, Guigui P, et al. Validation d'un outil de mesure des paramètres pelviens et rachidiens de l'équilibre sagittal du rachis [Validation of a tool to measure pelvic and spinal parameters of sagittal balance]. *Rev Chir Orthop Reparatrice Appar Mot*. 2003;89:218–27.
10. Copay AG, Glassman SD, Subach BR, Berven S, Schuler TC, Carreon LY. Minimum clinically important difference in lumbar spine surgery patients: a choice of methods using the Oswestry Disability Index, Medical Outcomes Study questionnaire Short Form 36, and pain scales. *Spine J*. 2008;8:968–74.
11. Zygourakis CC, Liu CY, Keefe M, et al. Analysis of national rates, cost, and sources of cost variation in adult spinal deformity. *Neurosurgery*. 2018;82:378–87.
12. Carreon LY, Kelly MP, Crawford CH III, et al. SRS-22R minimum clinically important difference and substantial clinical benefit after adult lumbar scoliosis surgery. *Spine Deform*. 2018; 6:79–83.
13. Champain S, Benchikh K, Nogier A, Mazel C, Guise J De, Skalli W. Validation of new clinical quantitative analysis software applicable in spine orthopaedic studies. *Eur Spine J*. 2006;15: 982–91.
14. Klineberg EO, Passias PG, Poorman GW, et al. Classifying complications: assessing adult spinal deformity 2-year surgical outcomes. *Global Spine J*. 2020;10:896–907.