Incremental cost-effectiveness of adult spinal deformity surgery: observed quality-adjusted life years with surgery compared with predicted quality-adjusted life years without surgery

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Object. Incremental cost-effectiveness analysis is critical to the efficient allocation of health care resources; however, the incremental cost-effectiveness ratio (ICER) of surgical versus nonsurgical treatment for adult spinal deformity (ASD) has eluded the literature, due in part to inherent empirical difficulties when comparing surgical and nonsurgical patients. Using observed preoperative health-related quality of life (HRQOL) for patients who later underwent surgery, this study builds a statistical model to predict hypothetical quality-adjusted life years (QALYs) without surgical treatment. The analysis compares predicted QALYs to observed postoperative QALYs and forms the resulting ICER.

Methods. This was a single-center (Baylor Scoliosis Center) retrospective analysis of consecutive patients undergoing primary surgery for ASD. Total costs (expressed in 2010 dollars) incurred by the hospital for each episode of surgical care were collected from administrative data and QALYs were calculated from the 6-dimensional Short-Form Health Survey, each discounted at 3.5% per year. Regression analysis was used to predict hypothetical QALYs without surgery based on preoperative longitudinal data for 124 crossover surgical patients with similar diagnoses, baseline HRQOL, age, and sex compared with the surgical cohort. Results were projected through 10-year follow-up, and the cost-effectiveness acceptability curve (CEAC) was estimated using nonparametric bootstrap methods.

Results. Three-year follow-up was available for 120 (66%) of 181 eligible patients, who were predominantly female (89%) with average age of 50. With discounting, total costs averaged \$125,407, including readmissions, with average QALYs of 1.93 at 3-year follow-up. Average QALYs without surgery were predicted to be 1.6 after 3 years. At 3- and 5-year follow-up, the ICER was \$375,000 and \$198,000, respectively. Projecting through 10-year follow-up, the ICER was \$80,000. The 10-year CEAC revealed a 40% probability that the ICER was \$80,000 or less, a 90% probability that the ICER was \$90,000 or less, and a 100% probability that the ICER was less than \$100,000.

Conclusions. Based on the WHO's suggested upper threshold for cost-effectiveness (3 times per capita GDP, or \$140,000 in 2010 dollars), the analysis reveals that surgical treatment for ASD is cost-effective after a 10-year period based on predicted deterioration in HRQOL without surgery. The ICER well exceeds the WHO threshold at earlier follow-up intervals, highlighting the importance of the durability of surgical treatment in assessing the value of surgical intervention. Due to the study's methodology, the results are dependent on the predicted deterioration in HRQOL without surgery. As such, the results may not extend to patients whose HRQOL would remain steady without surgery. Future research should therefore pursue a direct comparison of QALYs for surgical and nonsurgical patients to better understand the cost-effectiveness of surgery for the average ASD patient.

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KEY WORDS • adult spinal deformity • scoliosis • cost-effectiveness • health-related quality of life

BASED on the Nationwide Inpatient Sample, the total number of adult spinal deformity (ASD) surgeries more than doubled over the past decade, from

Abbreviations used in this paper: ASD = adult spinal deformity; CEAC = cost-effectiveness acceptability curve; HRQOL = health-related quality of life; ICER = incremental cost-effectiveness ratio; QALY = quality-adjusted life year; SF-6D = 6-dimensional Short-Form Health Survey.

9400 in 2000 to more than 20,600 in 2010 (<http://hcup-us.ahrq.gov/nisoverview.jsp>). This compares to just a 20% increase in the frequency of all other spine primary diagnosis codes over the same time period (from 675,500 in 2000 to 813,800 in 2010; <http://hcup-us.ahrq.gov/nisoverview.jsp>). Adult spinal deformity surgery is likely to increase in frequency with as much as 32% of the adult population suffering from scoliosis and a prevalence of 60% among the elderly.^{18–21}

In addition to increasing frequency, hospital costs of ASD surgery can easily exceed \$100,000 per patient after accounting for overhead allocation, readmissions, and complications following surgery.¹⁶ The real cost of treating adult scoliosis would be greater still, as these figures do not capture the large costs of outpatient care or prescription drugs, not to mention indirect costs incurred from lost productivity at work or family burden. As a result of increasing frequency and high costs of surgery, health care providers are under intense pressure to quantify the economic value of ASD and other complex spine surgeries.^{6,7,16}

Yet despite the importance of cost-effectiveness studies in ASD, to date there have been no published studies attempting to directly measure the incremental cost-effectiveness of surgical treatment for ASD. Research in this area has been hampered not only by access to reliable cost data and validated, utility-based quality-of-life outcomes, but also by the inherent empirical difficulties in estimating the impact of surgical versus nonsurgical treatment. In particular, it is known that nonsurgical patients differ from surgical patients in meaningful ways, specifically with regard to baseline health-related quality of life (HRQOL).^{1,4,8,11} Given the ethical restrictions on randomized surgical/nonsurgical trials, identifying the accurate benefit of surgical treatment on quality-adjusted life years (QALYs) requires careful empirical consideration.^{13,14,17,25}

The objective of this study was to assess the incremental cost-effectiveness of surgical versus nonsurgical treatment for ASD based on hypothetical predictions of QALYs for surgical patients as if surgery were never undertaken. This approach is intended to reflect the common argument that surgical treatment should be pursued while the patient can still recover from surgery and before the deformity increases and HRQOL further deteriorates. Intuitively, this argument may be most relevant for younger ASD patients, for whom treatment decisions are driven more by the deformity itself rather than degradation in quality of life.^{1,11,22}

Methods

This was a single-center retrospective study of consecutive ASD patients undergoing primary surgery with ICD-9 (International Classification of Diseases, Ninth Edition) principal diagnosis code 737.0–737.9 from January 2008 through June 2010 at Baylor Scoliosis Center in Plano, Texas. Patients younger than 18 years of age were excluded from the study. All patients underwent spinal fusion with a minimum of 3 levels fused.

Our measure of costs was the total costs incurred by the hospital for the episode of surgical care, expressed in 2010 dollars and totaled across the index surgery and any subsequent readmissions. Quality-adjusted life years were estimated from the 6-dimensional Short-Form Health Survey (SF-6D) and observed over a 3-year period, with HRQOL assessment at baseline (no more than 3 months prior to surgery for operative patients) and annually thereafter.^{2,3} Costs and QALYs were discounted at 3.5% annually.^{2,12}

To assess the incremental effect of surgical treatment

relative to nonsurgical treatment, a regression model was specified to predict hypothetical QALYs without surgery based on preoperative data. This model was estimated for a cohort of crossover surgical patients with similar diagnoses, baseline HRQOL, ages, and sex compared with the initial surgical cohort. This approach relies on data for patients with at least 2 preoperative HRQOL assessments who first visited the physician as nonoperative patients but ultimately underwent surgery after continued consultation.

Specifically, this approach estimates by ordinary least squares the following equation:

$$\text{HRQOL}_{t,i} = \alpha + Z_i\beta_1 + \text{HRQOL}_{t-1,i}\beta_2 + Y_i\beta_3 + \varepsilon_{t,i}$$

in which HRQOL at time t is estimated as a function of HRQOL at time $t-1$, along with the time elapsed (in years) from $t-1$ to t and additional observed patient characteristics (Z). The resulting coefficient estimates can be used to predict hypothetical HRQOL as if the patient had not undergone surgery, as a function of baseline HRQOL and other variables. Hypothetical QALYs without surgery were predicted 3 years into the future based on the regression model estimated in the equation above. Quality-adjusted life years through 5- and 10-year follow-up were then projected based on predicted QALYs as of year 3.

The regression analysis provides an estimate of the incremental improvement in QALYs from surgery compared with hypothetical QALYs if surgery had not taken place. The ratio of average discounted hospital costs to the discounted improvement in QALYs yields the estimated incremental cost-effectiveness ratio (ICER). We then estimated the associated 95% CIs, as well as cost-effectiveness acceptability curves (CEACs), using a non-parametric bootstrap technique with 5000 iterations. This technique iteratively samples, with replacement, individual costs and QALYs from the full data set. At each iteration we take the average costs of the bootstrap sample and estimate the incremental effect of surgery. The process yields a sample of 5000 costs and incremental QALYs from which to form the CEACs and 95% CIs.²⁴ All analyses were performed using Stata 12.1 (StataCorp LP), and institutional review board approval was obtained to conduct the study.

Results

This analysis relied on two separate cohorts of patients: 1) surgical patients with 3-year follow-up ($n = 120$ of 181 consecutive patients with baseline HRQOL); and 2) crossover patients with two HRQOL assessments available preoperatively ($n = 124$). Table 1 summarizes the HRQOL outcomes and patient demographics for each cohort.

Regression analysis was used to predict hypothetical QALYs without surgery based on preoperative data for the 124 crossover surgical patients. Following the equation listed above, the regression specified follow-up HRQOL as a function of a patient's initial HRQOL, age, sex, interactions between these 3 variables, and the time between initial HRQOL assessment and follow-up (range 4 months to 2 years). These regression results are summarized in Table 2. The results also satisfy a series of speci-

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TABLE 1: Summary of HRQOL outcomes and patient demographics for each patient cohort

Variable	Surgical Group	Crossover Group
female (%)	89	86
mean age $\pm$ SD (yrs)	50.531 $\pm$ 13.20	49.915 $\pm$ 15.68
baseline HRQOL $\pm$ SD	0.620 $\pm$ 0.12	0.614 $\pm$ 0.13
3-yr QALYs $\pm$ SD	1.931 $\pm$ 0.34	—
no. of patients	120	124

fication tests, including the Shapiro-Wilk test of normally distributed errors ($p = 0.28$), the Ramsey RESET test of omitted variables ($p = 0.50$), and the link test of proper model specification ($p = 0.99$).

We then applied the regression results from Table 2 to the observed data on the surgical cohort. Hypothetical QALYs were predicted through 1- and 2-year follow-up, and the percentage change from year 1 to year 2 was used to predict QALYs at years 3, 5, and 10. These hypothetical QALYs were then compared with the observed QALYs at 3-year follow-up, and the subsequent projections through 5- and 10-year follow-up, respectively.

The regression results in Table 2 predicted a hypothetical 1.60 QALYs without surgical treatment after 3-year follow-up, whereas an average of 1.93 QALYs were observed for this same patient group at 3 years following surgery (Table 1). Based on hospital costs of \$125,407, the ICER was estimated to be \$374,428 with a 95% CI of \$311,400 to \$455,600. Projecting through 5- and 10-year follow-up, the estimated ICERs were \$198,000 and \$80,387, respectively, with 95% CIs of \$167,400 to \$237,000 at 5-year follow-up and \$69,800 to \$93,400 at 10-year follow-up (Table 3).

The 10-year CEAC in Fig. 1 illustrates the probability that the dollar per QALY improvement falls below a given threshold value (the “willingness to pay” for surgical intervention). Each probability is calculated as the proportion of bootstrap-derived ICER estimates falling below a given cost-effectiveness threshold. For example, given a willingness-to-pay threshold of \$90,000 per

TABLE 2: Regression results for projected QALYs*

Variable	Coefficient	Standard Error	p Value
initial HRQOL	0.949	0.261	0.00
age	0.004	0.006	0.48
female	0.209	0.206	0.31
time from initial survey	-0.024	0.021	0.25
interaction terms			
age $\times$ initial HRQOL	-0.001	0.004	0.83
female $\times$ initial HRQOL	-0.192	0.203	0.35
age $\times$ female	-0.002	0.002	0.34
constant	-0.089	0.260	0.73
R ²	0.582		

* Ordinary least-squares regression of 124 crossover surgical patients. Age squared was also included as a covariate in the model but was excluded from the table for brevity.

TABLE 3: Incremental cost-effectiveness ratios and 95% CIs

Variable	3-Yr	5-Yr	10-Yr
cost (\$)	125,407	125,407	125,407
QALYs w/ surgery	1.93	3.11	5.71
QALYs w/o surgery	1.60	2.47	4.15
QALYs gained	0.335	0.633	1.560
ICER (\$)	374,428	198,000	80,387
lower 95% CI (\$)	311,400	167,400	69,800
upper 95% CI (\$)	455,600	237,000	93,400

QALY gained, the CEAC estimates a 90% probability that surgical intervention for ASD is cost-effective after 10-year follow-up provided HRQOL would deteriorate without surgery.

Discussion

Most of the cost-effectiveness studies currently available in the spine literature concern the cost-effectiveness of surgical treatment in the lumbar spine, including disc herniation and degenerative spondylolisthesis. For example, as part of the Spine Patient Outcomes Research Trial (SPORT), Tosteson et al. studied the cost-effectiveness of surgical versus nonsurgical treatment for lumbar disc herniation.²³ The authors estimated costs based on patient-reported utilization multiplied by Medicare per-unit allowable payment rates and measured outcomes as QALYs based on the EuroQol Group-5 Dimension (EQ-5D). The study reported an ICER of \$69,403 for all patients and an ICER of \$34,355 for Medicare patients. Based on direct costs only, the ICER increased to \$72,181 for all patients and \$37,285 for Medicare patients.

Glassman et al. analyzed the cost-effectiveness of single-level posterolateral lumbar fusion for 93 patients, with cost data based on actual reimbursements from third party payors and outcomes measured as QALYs based on the SF-6D.^{2,3,9} As part of the cost of surgery, the authors included outpatient visits up to 6 months after surgery. The authors reported an average reimbursement amount per QALY of \$164,261 after 1 year and \$154,865 after 2 years, although estimates varied depending on the patient cohort of interest.

Although baseline HRQOL is often cited as a major factor for surgical decision making, it is certainly possible that physicians look to additional, unobserved factors in deciding whether to discuss surgical options with patients. Our approach incorporates one such factor—namely, the belief that surgery should be pursued earlier while the patient can sufficiently recover and before HRQOL significantly deteriorates. As such, the underlying assumption is that the degradation in HRQOL for crossover patients would be the same, conditional on baseline HRQOL and other patient characteristics, for other patients who underwent surgery more quickly (that is, without a period of surveillance) and that this same degree of deterioration in HRQOL persists throughout the follow-up time frame. If our assumptions are not valid, and nonsurgical patients would have remained at their baseline HRQOL

Fig. 1. Incremental CEAC of surgical treatment of ASD over a 10-year follow-up.

values or improved in HRQOL over time, then prior work has shown that surgical treatment would not be as cost-effective. In the absence of any deterioration, ongoing research has shown that ICERs for ASD surgery range from \$276,000 to \$476,000.¹⁵

Intuitively, several factors specific to spinal deformity likely influence the cost-effectiveness of ASD surgery compared with other spine studies in the literature. First, baseline HRQOL for ASD patients is higher on average than that of other spine surgery patients. For example, Glassman et al. reported a baseline SF-6D score of 0.5 and a postoperative SF-6D of 0.62 after 1 year.⁹ In our analysis, average SF-6D at baseline was 0.62 among surgical patients, with SF-6D scores after 1 year averaging 0.69.

The high baseline HRQOL scores observed in our data are similar to those of other multicenter spine deformity studies. In particular, Bess et al.,¹ Bridwell et al.,⁴ and Glassman et al.¹⁰ report average baseline Oswestry Disability Index scores for surgical spine deformity patients of 33, 37, and 34, respectively, much lower (lesser disability) than the average Oswestry Disability Index score of 56 reported in Glassman et al.⁹ in their 2012 study of single-level posterolateral lumbar fusion. Carreon et al.⁵ also reported an average baseline SF-6D of 0.53 among patients with scoliosis, which was the highest average baseline score among all diagnostic categories considered.

Second, our analysis includes HRQOL assessments for patients with readmissions subsequent to their primary surgery. For example, average QALYs after 3 years were 1.71 among patients with a readmission ($n = 23$), compared with an average of 1.98 among patients without a readmission. The total hospital costs for those with a readmission averaged \$183,000 compared with less than \$112,000 for patients without a readmission. Given the invasiveness and painful recovery following ASD surgery, a return to surgery reduces average QALYs while also adding to the average cost of surgery. Readmissions may therefore have a substantial effect on the overall ICERs, and hence on the estimated value of surgical treatment for the average ASD patient.

A final point concerns our measure of costs. In this analysis, we have considered only the hospital costs incurred for surgery and have not considered the cost of

nonsurgical treatment. Our estimate of incremental costs is therefore taken solely as the direct costs of surgery incurred by the hospital, including overhead but excluding physician's fees. This exclusion is appropriate in a general sense, given that surgical costs are fundamentally incremental when compared with costs for nonsurgical patients; however, to the extent that nonsurgical costs incurred through physician visits, long-term physical therapy, or extended prescription drug usage differ from similar types of costs for surgical patients, our measure of incremental costs will not fully reflect differences in costs between the two groups. Over extended follow-up, the difference in costs between surgical and nonsurgical treatment may decrease in magnitude as nonsurgical treatment requires prolonged prescription drug usage, decreases productivity, and may even require surgical intervention at a later age. Conversely, surgical treatment costs may also increase over time due to future revisions or complications, but such increases would be relatively small on average.¹⁶ Additional indirect cost/benefit considerations associated with variation in productivity and absenteeism would further improve our analysis of surgical and nonsurgical treatment over an extended time frame.

Conclusions

Our analysis reveals two important findings with regard to the cost-effectiveness of surgical treatment for scoliosis and spinal deformity. First, the analysis estimates an ICER of \$80,387 per QALY gained from surgery for the average ASD patient over a 10-year follow-up. Based on the WHO's suggested upper threshold for cost-effectiveness (3 times per capita GDP, or \$140,000 in 2010 dollars), the analysis reveals that surgical treatment for ASD is cost-effective after a 10-year period. These results represent a best-case scenario for an average ASD patient whose HRQOL would deteriorate under nonoperative care. At earlier follow-up intervals, the ICER well exceeds the WHO threshold, highlighting the importance of extended follow-up and accurate HRQOL prediction in the appropriate economic evaluation of surgical treatment for ASD.

From a policy standpoint, our findings may also support a brief period of surveillance for patients with relatively high baseline HRQOL. Provided we can identify patients whose HRQOL would further deteriorate without surgery, the results indicate that surgical treatment can be a cost-effective intervention for such patients. If deterioration in HRQOL is clearly documented prior to surgery, then the economic value of surgical intervention for such patients could be more easily supported and quantified.

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References

1. Bess S, Boachie-Adjei O, Burton D, Cunningham M, Shaffrey C, Shelokov A, et al: Pain and disability determine treatment modality for older patients with adult scoliosis, while deformity guides treatment for younger patients. **Spine (Phila Pa 1976)** **34**:2186–2190, 2009
2. Brazier J, Ratcliffe J, Tsuchiya A, Salmon J: **Measuring and Valuing Health Benefits for Economic Evaluation**. Oxford: Oxford University Press, 2007
3. Brazier J, Roberts J, Deverill M: The estimation of a preference-based measure of health from the SF-36. **J Health Econ** **21**:271–292, 2002
4. Bridwell KH, Glassman S, Horton W, Shaffrey C, Schwab F, Zebala LP, et al: Does treatment (nonoperative and operative) improve the two-year quality of life in patients with adult symptomatic lumbar scoliosis: a prospective multicenter evidence-based medicine study. **Spine (Phila Pa 1976)** **34**:2171–2178, 2009
5. Carreon LY, Djurasovic M, Canan CE, Burke LO, Glassman SD: SF-6D values stratified by specific diagnostic indication. **Spine (Phila Pa 1976)** **37**:E804–E808, 2012
6. Deyo RA, Mirza SK: The case for restraint in spinal surgery: does quality management have a role to play? **Eur Spine J** **18** (Suppl 3):331–337, 2009
7. Deyo RA, Nachemson A, Mirza SK: Spinal-fusion surgery—the case for restraint. **N Engl J Med** **350**:722–726, 2004
8. Glassman SD, Berven S, Kostuik J, Dimar JR, Horton WC, Bridwell K: Nonsurgical resource utilization in adult spinal deformity. **Spine (Phila Pa 1976)** **31**:941–947, 2006
9. Glassman SD, Polly DW, Dimar JR, Carreon LY: The cost effectiveness of single-level instrumented posterolateral lumbar fusion at 5 years after surgery. **Spine (Phila Pa 1976)** **37**:769–774, 2012
10. Glassman SD, Schwab F, Bridwell KH, Shaffrey C, Horton W, Hu S: Do 1-year outcomes predict 2-year outcomes for adult deformity surgery? **Spine J** **9**:317–322, 2009
11. Glassman SD, Schwab FJ, Bridwell KH, Ondra SL, Berven S, Lenke LG: The selection of operative versus nonoperative treatment in patients with adult scoliosis. **Spine (Phila Pa 1976)** **32**:93–97, 2007
12. Gray AM, Clarke PM, Wolstenholme JL, Wordsworth S: **Applied Methods of Cost-Effectiveness Analysis in Health Care**. Oxford: Oxford University Press, 2011
13. Hoch JS, Briggs AH, Willan AR: Something old, something new, something borrowed, something blue: a framework for the marriage of health econometrics and cost-effectiveness analysis. **Health Econ** **11**:415–430, 2002
14. Manca A, Hawkins N, Sculpher MJ: Estimating mean QALYs in trial-based cost-effectiveness analysis: the importance of controlling for baseline utility. **Health Econ** **14**:487–496, 2005
15. McCarthy I, O'Brien M, Ames CP, Errico TJ, Kim HJ, Mundis GM Jr, et al: Cost-utility analysis of surgical treatment for adult spinal deformity. **Spine J** **13**:S107–S108, 2013
16. McCarthy IM, Hostin RA, O'Brien MF, Fleming NS, Ogola G, Kudyakov R, et al: Analysis of the direct cost of surgery for four diagnostic categories of adult spinal deformity. **Spine J** **13**:1843–1848, 2013
17. Nixon RM, Thompson SG: Methods for incorporating covariate adjustment, subgroup analysis and between-centre differences into cost-effectiveness evaluations. **Health Econ** **14**:1217–1229, 2005
18. Robin GC, Span Y, Steinberg R, Makin M, Menczel J: Scoliosis in the elderly: a follow-up study. **Spine (Phila Pa 1976)** **7**:355–359, 1982
19. Schwab F, Dubey A, Gamez L, El Fegoun AB, Hwang K, Pagala M, et al: Adult scoliosis: prevalence, SF-36, and nutritional parameters in an elderly volunteer population. **Spine (Phila Pa 1976)** **30**:1082–1085, 2005
20. Schwab F, Dubey A, Pagala M, Gamez L, Farcy JP: Adult scoliosis: a health assessment analysis by SF-36. **Spine (Phila Pa 1976)** **28**:602–606, 2003
21. Schwab FJ, Lafage V, Farcy JP, Bridwell KH, Glassman S, Shainline MR: Predicting outcome and complications in the surgical treatment of adult scoliosis. **Spine (Phila Pa 1976)** **33**:2243–2247, 2008
22. Smith JS, Shaffrey CI, Glassman SD, Berven SH, Schwab FJ, Hamill CL, et al: Risk-benefit assessment of surgery for adult scoliosis: an analysis based on patient age. **Spine (Phila Pa 1976)** **36**:817–824, 2011
23. Tosteson AN, Tosteson TD, Lurie JD, Abdu W, Herkowitz H, Andersson G, et al: Comparative effectiveness evidence from the spine patient outcomes research trial: surgical versus nonoperative care for spinal stenosis, degenerative spondylolisthesis, and intervertebral disc herniation. **Spine (Phila Pa 1976)** **36**:2061–2068, 2011
24. Willan AR, Briggs AH: **Statistical Analysis of Cost-Effectiveness Data**. West Sussex, UK: John Wiley & Sons, 2006
25. Willan AR, Briggs AH, Hoch JS: Regression methods for covariate adjustment and subgroup analysis for non-censored cost-effectiveness data. **Health Econ** **13**:461–475, 2004

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