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CLINICAL ARTICLE

# Cost-effectiveness of posterior lumbar interbody fusion and/or transforaminal lumbar interbody fusion for grade 1 lumbar spondylolisthesis: a 5-year Quality Outcomes Database study

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**OBJECTIVE** Posterior lumbar interbody fusion (PLIF) and/or transforaminal lumbar interbody fusion (TLIF), referred to as "PLIF/TLIF," is a commonly performed operation for lumbar spondylolisthesis. Its long-term cost-effectiveness has not been well described. The aim of this study was to determine the 5-year cost-effectiveness of PLIF/TLIF for grade 1 degenerative lumbar spondylolisthesis using prospective data collected from the multicenter Quality Outcomes Database (QOD).

**METHODS** Patients enrolled in the prospective, multicenter QOD grade 1 lumbar spondylolisthesis module were included if they underwent single-stage PLIF/TLIF. EQ-5D scores at baseline, 3 months, 12 months, 24 months, 36 months, and 60 months were used to calculate gains in quality-adjusted life years (QALYs) associated with surgery relative to preoperative baseline. Healthcare-related costs associated with the index surgery and related reoperations were calculated using Medicare reimbursement–based cost estimates and validated using price transparency diagnosis-related group (DRG) charges and Medicare charge-to-cost ratios (CCRs). Cost per QALY gained over 60 months postoperatively was assessed.

**RESULTS** Across 12 surgical centers, 385 patients were identified. The mean patient age was 60.2 (95% CI 59.1–61.3) years, and 38% of patients were male. The reoperation rate was 5.7%. DRG 460 cost estimates were stable between our Medicare reimbursement–based models and the CCR-based model, validating the focus on Medicare reimbursement. Across the entire cohort, the mean QALY gain at 60 months postoperatively was 1.07 (95% CI 0.97–1.18), and the mean cost of PLIF/TLIF was $31,634. PLIF/TLIF was associated with a mean 60-month cost per QALY gained of $29,511. Among patients who did not undergo reoperation (n = 363), the mean 60-month QALY gain was 1.10 (95% CI 0.99–

**ABBREVIATIONS** CCR = charge-to-cost ratio; CPT = Current Procedural Terminology; DRG = diagnosis-related group; PLIF = posterior lumbar interbody fusion; PLIF/TLIF = PLIF and/or TLIF; QALY = quality-adjusted life year; QOD = Quality Outcomes Database; TLIF = transforaminal lumbar interbody fusion; WTP = willingness-to-pay.

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1.20), and cost per QALY gained was $27,591. Among those who underwent reoperation (n = 22), the mean 60-month QALY gain was 0.68 (95% CI 0.21–1.15), and the cost per QALY gained was $80,580.

**CONCLUSIONS** PLIF/TLIF for degenerative grade 1 lumbar spondylolisthesis was associated with a mean 60-month cost per QALY gained of $29,511 with Medicare fees. This is far below the well-established societal willingness-to-pay threshold of $100,000, suggesting long-term cost-effectiveness. PLIF/TLIF remains cost-effective for patients who undergo reoperation.

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**KEYWORDS** Quality Outcomes Database; lumbar spondylolisthesis; posterior lumbar interbody fusion; transforaminal lumbar interbody fusion; cost-effectiveness; quality of life

Degenerative lumbar spondylolisthesis is a leading cause of low-back and leg pain with an estimated prevalence of 11.5% in the US adult population.[1,2] For patients in whom conservative management fails, fusion with decompression has been associated with improvements in pain, disability, and quality of life.[1,3–5] Posterior lumbar interbody fusion (PLIF) and transforaminal lumbar interbody fusion (TLIF) are commonly employed techniques given their ability to provide anterior column support, restore lumbar lordosis, provide additional surface area for fusion, and increase foraminal height compared with posterolateral fusion alone.[6,7]

Rising healthcare costs have led to increased scrutiny of the value of lumbar fusion procedures. However, many of these studies have been limited by small and heterogeneous patient populations, disparate methods for calculating cost and efficacy, and relatively brief follow-up.[8–11] Randomized controlled trials are difficult to apply to surgical populations due to narrow inclusion criteria, uncertain generalizability, and crossover. Prospective multicenter registries encompassing real-world practice patterns and containing reliable long-term clinical follow-up are well suited to addressing the societal value of surgery.

The purpose of this study was to determine the 5-year cost-effectiveness of PLIF and/or TLIF (PLIF/TLIF) for grade 1 degenerative lumbar spondylolisthesis using prospective data collected from the multicenter Quality Outcomes Database (QOD). The calculated cost per quality-adjusted life year (QALY) was placed into the context of widely accepted willingness-to-pay (WTP) thresholds in the US.

## Methods

### Study Design and Patient Population

This study analyzed prospectively collected data from the QOD lumbar module. An augmented lumbar spondylolisthesis dataset was created by pooling data from the 12 highest-enrolling QOD sites. These data were audited centrally and by the individual sites. This dataset was queried for patients 18 years and older who underwent single-stage PLIF/TLIF for Meyerding grade 1 lumbar degenerative spondylolisthesis (Fig. 1). Patients were excluded if they underwent an anterior or lateral procedure concurrently or in a separate stage.

Demographic variables included age, sex, BMI, American Society of Anesthesiologists classification, comorbid conditions, and smoking status. Rates of complications and reoperations related to the index surgery were also recorded. EQ-5D scores were collected at baseline and postoperatively at 3 months, 12 months, 24 months, 36 months, and 60 months.

### Quality-Adjusted Life Years

EQ-5D scores at baseline and postoperatively at 3 months, 12 months, 24 months, 36 months, and 60 months were used to calculate QALYs with US valuation using the area under the curve method.[12–14] This entails multiplying each EQ-5D score by the time spent in that state and then summing these values to calculate total QALYs. To calculate QALYs gained with surgery relative to baseline, each patient's preoperative QALY was extrapolated over 60 months and subtracted from the total 60-month QALY. Multivariate imputation by chained equations (MICE) was performed with the "mice" package using R software (version 4.2.3, R Foundation for Statistical Computing) for missing EQ-5D values, and the final imputed data were used for the analysis. The MICE procedure involves running a series of regression models with the variable with missing data (EQ-5D) modeled dependent on the observed values in the dataset.[15]

### Base Cost Model

Costs were calculated using Medicare reimbursement–based models and accounted for inpatient or outpatient care. Costs for inpatient care (> 1 hospital night) were calculated using diagnosis-related group (DRG) 460 (spinal fusion except cervical without complication or comorbidity) reimbursement data specific to each participating institution. Patients with complications were upgraded to DRG 459 (spinal fusion except cervical with major complication or comorbidity).[16] All noninfectious reoperations were assumed to require another DRG 460 payment, and all infectious revisions were assumed to fall under DRG 858 (postoperative infection requiring operating room procedure without complication or comorbidity).

Costs for outpatient care (0 or 1 hospital nights) were derived from national Current Procedural Terminology (CPT) reimbursement Medicare allowable rates on the physician fee schedule.[17] For outpatient surgery, anesthesia costs were included based on the duration of surgery, and overnight costs were included based on length of stay and known average hospital day costs for each participating institution's home state.[18,19] Outpatient surgical costs retained the incremental DRG increase for a major complication and all revisions were still paid for via the DRG reimbursement model.

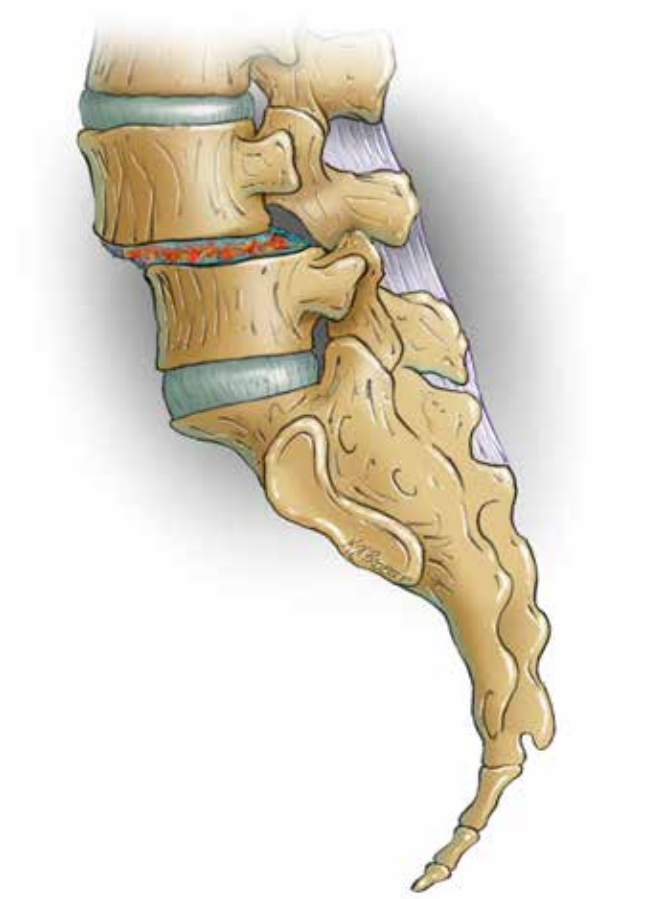

**FIG. 1.** Illustration of L4–5 Meyerding grade 1 degenerative spondylolisthesis. © Praveen Mummaneni, published with permission.

**TABLE 1. Baseline demographics of 385 patients who underwent PLIF/TLIF**

| | Value |
|---|---|
| Mean age, yrs (95% CI) | 60.2 (59.1–61.3) |
| Male sex | 147 (38.2) |
| Mean BMI, kg/m$^2$ (95% CI) | 31 (30.4–31.7) |
| ASA class | |
| I | 16 (4.3) |
| II | 198 (53.8) |
| III | 150 (40.8) |
| IV | 4 (1.1) |
| CAD | 42 (10.9) |
| Diabetes | 59 (15.3) |
| Osteoporosis | 27 (7) |
| Anxiety | 68 (17.7) |
| Depression | 88 (22.9) |
| Current smoker | 49 (12.7) |
| Private insurance | 216 (56.1) |
| Workers' compensation | 19 (4.9) |
| Employed & working | 159 (41) |
| Any motor deficit | 79 (20.5) |
| Independently ambulatory | 348 (90.4) |
| Symptom duration <3 mos | 5 (1.3) |

ASA = American Society of Anesthesiologists; CAD = coronary artery disease. Values are presented as the number of patients (%) unless stated otherwise.

### High and Low Models for Sensitivity Analysis

An alternative, less expensive model was calculated based on CPT, length of stay, and anesthesia time without any adjustment for complications. An alternative, more expensive model assumed all payments (inpatient and outpatient) were paid by DRGs. Because Medicare often reimburses hospitals below cost, both the alternative models were multiplied by known reimbursement-to-cost ratios from the American Hospital Association.[20]

### Alternative DRG-Based Validation Model

The Medicare reimbursement–based models using DRG 460 were validated against hospital charges for each participating center adjusted to general cost by the latest available hospital-wide charge-to-cost ratios (CCRs) from the Centers for Medicare & Medicaid Services Hospital Provider Cost Report for each participating hospital.[21] Charges were based on price transparency data from each participating hospital's DRG 460 listed charges or self-pay rates from Turquoise Health if charges were not listed on the website.[22–24]

### Cost-Effectiveness

Cost-effectiveness was calculated by dividing cost by QALYs gained over 60 months postoperatively. Based on complication and revision subgroups, a tree diagram cost-effectiveness model (TreeAge Healthcare Pro 2023) was created. Sensitivity analysis was performed using the high and low reimbursement models and modeling wide ± 25% changes for effectiveness as well as ± 20% changes for revision and complication rates. While there is no official WTP threshold in the US, various studies have suggested that the threshold ranges between $50,000 and $100,000, with more recent analyses suggesting that the threshold should be higher than $200,000. As $100,000 is a commonly employed threshold, in our analysis, we utilized a WTP of $100,000.[25–27]

## Results

### Demographics

Across 12 surgical centers, 385 patients were identified who underwent PLIF/TLIF for degenerative grade 1 lumbar spondylolisthesis. The mean patient age was 60.2 (95% CI 59.1–61.3) years, and 38% of patients were male. The mean BMI was 31 (95% CI 30.4–31.7) kg/m$^2$ (Table 1). The rate of related reoperations was 5.7% (n = 22), and the rate of any complication was 7.0% (n = 27).

### Cost

The base Medicare reimbursement model incorporating DRG-based reimbursement for inpatient surgery and CPT-based reimbursement for outpatient surgery resulted in a total cost of $12,179,114 and an average cost of $31,634 per patient. The lower-cost, CPT-based model

**TABLE 2. Cost-effectiveness summary**

| | Surgical Costs (base model) | | | QALYs Gained | | Costs/QALY | | | |
|---|---|---|---|---|---|---|---|---|---|
| | No. of Patients | Total | Average | Total | Average | Cost/QALY | % <$100,000/QALY | Low Cost/QALY | High Cost/QALY |
| Total | 385 | $12,179,114 | $31,634 | 412.69 | 1.07 | $29,511 | 76% | $14,178 | $38,346 |
| Revision | | | | | | | | | |
| No | 363 | $10,973,734 | $30,231 | 397.73 | 1.10 | $27,591 | 78% | $12,528 | $35,682 |
| Yes | 22 | $1,205,380 | $54,790 | 14.96 | 0.68 | $80,580 | 55% | $58,050 | $109,194 |
| Complication | | | | | | | | | |
| No | 358 | $10,657,436 | $29,769 | 391.13 | 1.09 | $27,248 | 78% | $13,522 | $35,307 |
| Yes | 27 | $1,521,678 | $56,358 | 21.56 | 0.80 | $70,566 | 59% | $26,077 | $93,483 |
| Revision & Complication | | | | | | | | | |
| None | 344 | $9,908,968 | $28,805 | 379.70 | 1.10 | $26,097 | 78% | $12,192 | $33,702 |
| Both | 8 | $456,913 | $57,114 | 3.53 | 0.44 | $129,394 | 50% | $59,156 | $175,724 |

Cost/QALY represents mean cost/mean QALY gained for each row. Low and high cost/QALY represent the lower-cost (CPT-based) and higher-cost (DRG-based) models.

showed an average cost of $15,198. The higher-cost, DRG-based model showed an average cost of $41,105.

Of note, base model costs were higher in patients who had complications ($56,358/patient) and patients who required reoperation ($54,790/patient). Patients who had complications and reoperations had the highest average costs ($57,114/patient) (Table 2).

External validation of our Medicare reimbursement–based models was performed by comparing a DRG 460 CCR-based model to our current DRG 460 Medicare reimbursement models, averaged across each participating hospital and unweighted by number of contributed patients. The average charge/self-pay rate across this study's participating hospitals was $163,918, and the average CCR was 0.231. The mean DRG 460 cost-converted price transparency estimate was $37,359 (95% CI $27,069–$47,649), similar to the mean DRG Medicare reimbursement that comprises the inpatient portion of our base model ($34,702 [95% CI $30,378–$39,026], p = 0.645) and the mean DRG Medicare reimbursement adjusted for Medicare underpayment used in our high-cost model ($41,312 [95% CI $36,164–$46.460], p = 0.508) (Fig. 2). Because there was no statistical difference between the CCR-based model and our Medicare reimbursement–based models, we con-

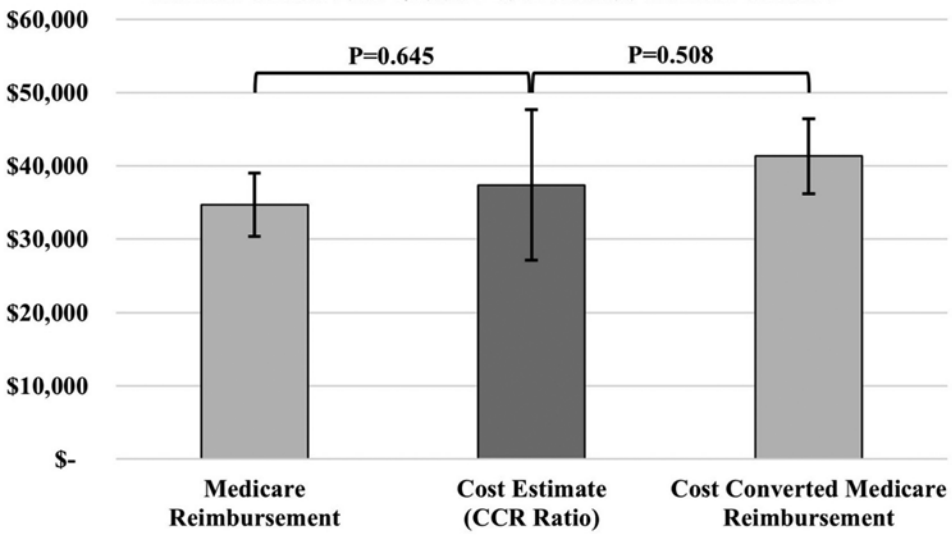


**FIG. 2.** Spinal fusion cost estimates (DRG 460). Comparison of mean Medicare reimbursement–based cost estimates (*light gray*) to Medicare CCR methodology (*dark gray*) for each participating hospital. *Error bars* indicate the 95% CIs. The *left bar* represents the base Medicare reimbursement model (DRG 460 Medicare reimbursement only, outpatient CPT reimbursement excluded). The *middle bar* represents cost estimates derived from each hospital's published charges/self-pay rates (DRG 460) converted to cost estimates via the latest Medicare ratio of estimated costs to charges for each hospital that accepts Medicare patients. The average charge/self-pay rate across this study's participating hospitals was $163,918, and the average CCR was 0.231. The *right bar* represents the high-cost model that adjusts the Medicare reimbursement for estimated Medicare underpayment. All cost estimates were normally distributed via Shapiro-Wilk test and compared using the Student t-test. Mean estimates were averaged across institutions, not weighted by number of contributed patients by each institution.

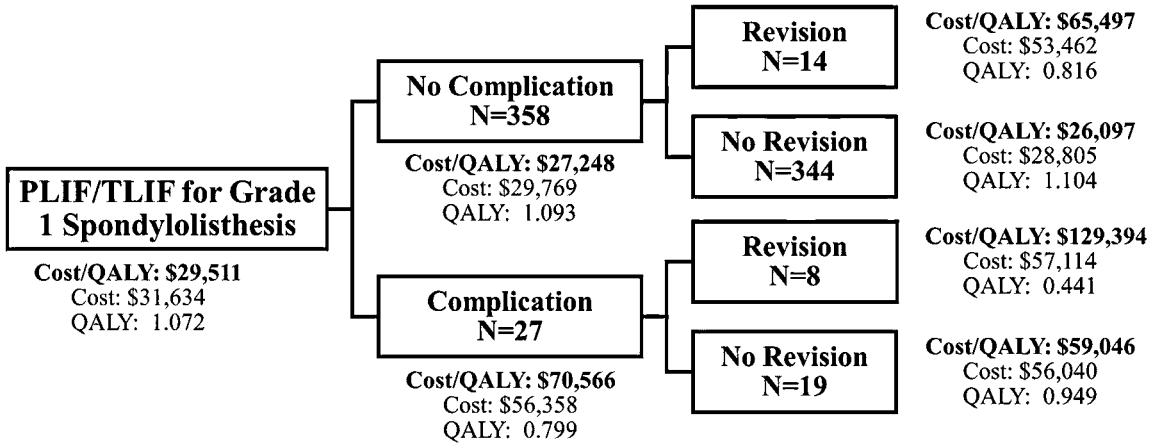


**FIG. 3.** Single-arm tree diagram model based on complications and revisions.

sidered our models to be validated by another common metric that would already be included in our sensitivity analysis.[23]

### Quality-Adjusted Life Years

Across the entire cohort, the mean QALY gain at 60 months postoperatively was 1.07 (95% CI 0.97–1.18). QALYs gained were lower in patients with complications (0.80) and revisions (0.68). There were lower but still positive mean QALY gains in patients who had both complications and reoperations (0.44) (Table 2).

### Cost-Effectiveness

The base Medicare reimbursement model showed an average cost per QALY of $29,511, well below the $100,000 WTP threshold. The base model even outperformed the highly conservative $50,000/QALY threshold.[25] Higher average cost per QALY was observed in patients with complications ($70,566/QALY) and those who underwent reoperation ($80,580/QALY). The only subgroup that did not meet cost-effectiveness on average at a WTP of $100,000 was the group of patients who had both complications and reoperations ($129,394/QALY), although these patients still gained an average of 0.44 QALYs relative to baseline (Table 2, Fig. 3). Sensitivity analysis (Fig. 4) showed that no single variable could make PLIF/TLIF cost-ineffective despite widely tested changes in costs (high/low models), QALYs (± 25% changes), and prob-

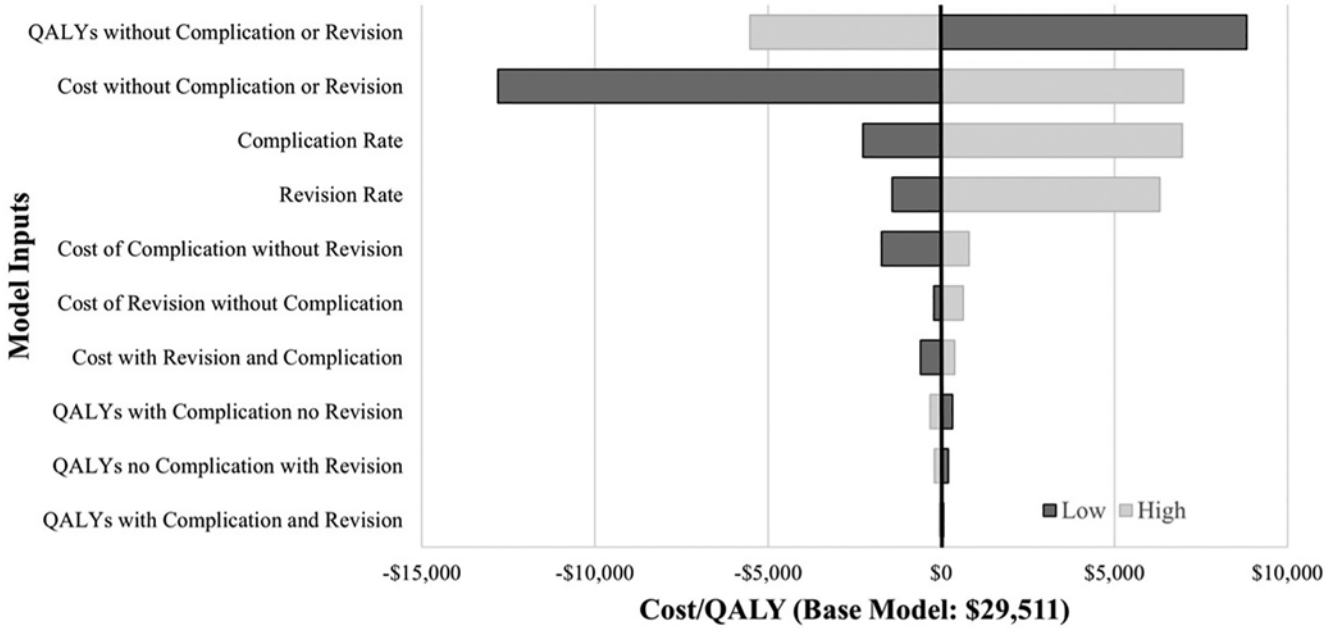


**FIG. 4.** Sensitivity analysis: cost per QALY change from base cost model ($29,511). This measures the overall model impact of variation in each input. Costs were measured according to the high- and low-cost models. QALYs were adjusted up or down by 25 percentage points. Probability of complications and revisions were measured with wide ± 20 absolute percentage points (e.g., 5.71% revision rate ranged from 0% to 25.71%).

ability of complications or revisions (± 20% changes) (Fig. 4). Finally, an analysis of the percentage of patients with a cost per QALY < $100,000 in each subgroup showed that overall, 76% of patients had cost-effective outcomes. Even 50% of patients who had both complications and revisions had a cost-effective outcome over 5 years (Table 2).

## Discussion

Prior efforts to estimate the value of fusion surgery for lumbar spinal pathology have been limited by small sample sizes, heterogeneous patient populations, disparate methods for calculating cost and efficacy, and relatively brief follow-up. In particular, the cost-effectiveness of PLIF/TLIF for spondylolisthesis has not been well described. This technique continues to grow in utilization because of its ability to provide anterior column support, restore lumbar lordosis, provide additional surface area for fusion, and increase foraminal height compared with posterolateral fusion alone. The QOD Study Group has previously published that TLIF for degenerative grade 1 spondylolisthesis is associated with improvements in back pain, leg pain, disability, and quality of life through 60 months postoperatively.[5]

The efficacy metric employed in cost-effectiveness analysis is the QALY, which accounts for both quality of life and the time spent in that health state. It is commonly derived from the validated health state utility questionnaire EQ-5D.[14] Of course, an assessment of clinical efficacy must be accompanied by an estimation of cost to determine the cost-effectiveness of any intervention. A well-established WTP threshold is $100,000 per QALY gained.[25,26] Medicare fee-for-service administrative pricing is readily available, while private payor rates are negotiated with differing facilities and surgeons, leading to substantial variability. Medicare frequently reimburses below cost, and studies with administrative prices often do not reflect real-world costs.[20,28] Therefore, we took the additional step of using mixed DRG and CPT reimbursement for our base model, where many studies use only lower CPT-based reimbursement. Likewise, our lower-cost, CPT-based model also incorporated estimated anesthesia reimbursement, higher Medicare allowable reimbursement rates instead of base reimbursement rates, estimated costs for each hospital day, and conversion to cost based on known estimates of Medicare underpayment. As a result, our direct cost-effectiveness estimates were likely highly conservative, as even our lower-end CPT-based estimates exceed most other CMS-based cost estimates.

Our analysis took the additional step of validating our Medicare reimbursement models with a model based on estimated charges/self-pay rates and Medicare CCRs for each participating hospital. This additional analysis takes advantage of growing research on healthcare costs and hospital price transparency.[23,24] We showed that this CCR estimate is captured within our sensitivity analysis between our base and our high-cost Medicare reimbursement–based models and would therefore already be included within our sensitivity analysis. In addition to direct costs, indirect costs related to lost wages and productivity contribute to the total cost of surgery. Indirect costs tend to be highly variable and reliant on patient recall and have been excluded from this analysis.

Adogwa et al. retrospectively studied 45 patients who underwent TLIF for grade 1 degenerative lumbar spondylolisthesis at a single academic medical center.[8] They calculated a mean cost of $36,836 and a mean QALY gain of 0.86 over 2 years postoperatively. TLIF was therefore demonstrated to be cost-effective with a mean cost per QALY of $42,854. Their cost calculations included both direct costs using the Medicare fee schedule and indirect costs associated with missed work. While we only included direct costs in our estimates, much of their indirect costs are obtained by patient recall, which is highly prone to bias. We do agree with their general conclusions, but our relative strengths include a much larger patient population, multicenter enrollment, and longer follow-up out to 5 years postoperatively.

Prior studies have also compared the cost-effectiveness of PLIF/TLIF to posterolateral fusion alone for lumbar spondylolisthesis. In 2016, Carreon et al. utilized the QOD to show greater health utility gains in the TLIF group compared with the posterolateral fusion group at 1 year postoperatively.[29] At a cost per QALY threshold of $100,000, their cost models demonstrated that TLIF would be cost-prohibitive compared with posterolateral fusion at a surgical cost of $4830 above that of posterolateral fusion using SF-6D–based QALYs and $2960 using EQ-5D–based QALYs. At the time of the study, the authors were limited to 101 patients, isthmic and degenerative spondylolisthesis were not distinguished from each other in the database, and follow-up was 1 year. Future studies with the current database have the potential to show a greater advantage of TLIF compared with other surgical approaches with larger sample sizes and longer follow-up. Importantly, the longer follow-up will demonstrate the effect of reoperations on cost-effectiveness.

To our knowledge, our study is the largest to demonstrate the cost-effectiveness of PLIF/TLIF for grade 1 degenerative lumbar spondylolisthesis. Additional strengths include prospectively acquired registry data, a 60-month follow-up period showing the durability of health utility gains, and representation across multiple practice patterns and geographic regions in the US. Our cost calculations differentiated between inpatient and outpatient surgery, were adjusted for geography for DRG reimbursement and length of stay costs, and incorporated costs associated with complications and related reoperations. The costs of related reoperations distinguished between infectious and noninfectious indications (e.g., adjacent-segment disease, pseudarthrosis). Our decision to assign DRG 460 to all noninfectious reoperations is designed to provide conservative (i.e., higher) cost estimates. We performed robust sensitivity analyses with low- and high-cost models, and overall use of TLIF for grade 1 spondylolisthesis remained cost-effective regardless of cost model or revision/complication rates.

There are some limitations to our study. We did not have a control group for comparison. Our study design assumed that the preoperative QALY was the maximal QALY obtained from nonsurgical management. We then assumed all gains in QALY were the result of surgery. This is a com-

mon and well-accepted assumption, which also avoids the artificial elevation of QALY for a medical control group that by definition improves in "as treated" analysis.[8,30] This inflation in QALYs was seen in the cost analysis of the control group in the Spine Patient Outcomes Research Trial (SPORT).[31] Next, although patient-reported outcomes were collected prospectively, cost data were not. Costs were estimated using the Medicare fee schedule and with DRG and CPT code assumptions. Although we attempted to be conservative in our Medicare reimbursement–based models by incorporating DRGs (instead of just CPTs) and by validating our model using publicly available charges converted to costs, these models are likely less accurate than internal cost data and our validation model could be skewed by using estimated charges for each hospital, without detailed breakdown of exact charges, and by use of hospital-wide CCRs based on publicly available data. Our cost estimates did not include out-of-pocket, medication (e.g., narcotics, antibiotics), or radiology-related costs. They also did not include indirect costs associated with lost wages and productivity, but these are highly variable and prone to patient recall bias.

## Conclusions

PLIF/TLIF for grade 1 degenerative lumbar spondylolisthesis was associated with a mean 60-month cost per QALY gained of $29,511 using Medicare reimbursement–based models. This is far below the well-established societal WTP threshold of $100,000, suggesting cost-effectiveness of the operation. PLIF/TLIF remained cost-effective even for patients who underwent reoperation.

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Conception and design: Yee, Liles, DiGiorgio, Potts, Knightly, Bydon, Chan, Meyer, Slotkin, Haid, Glassman, Virk. Acquisition of data: Liles, Johnson, Coric, Potts, Bisson, Knightly, Foley, ME Shaffrey, Bydon, Chan, Asher, CI Shaffrey, Slotkin, Wang, Glassman, Virk, Mummaneni, Park. Analysis and interpretation of data: Yee, Liles, Johnson, DiGiorgio, ME Shaffrey, Chan, Slotkin, Haid, Virk, Park. Drafting the article: Yee, Liles, Ambati, Alan. Critically revising the article: Yee, Liles, Ambati, DiGiorgio, Alan, Fu, Foley, ME Shaffrey, Bydon, Chan, CI Shaffrey, Wang, Haid, Glassman, Park. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Yee. Statistical analysis: Liles, Johnson. Administrative/technical/material support: Liles, Bydon, CI Shaffrey, Glassman. Study supervision: Liles, Potts, Bisson, Bydon, Mummaneni.

## Supplemental Information

### Previous Presentations

This paper was presented at the 2024 AANS/CNS Section on Disorders of the Spine and Peripheral Nerves, Las Vegas, NV, February 21–24, 2024, and was awarded the Kuntz Scholar Award.

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