Cost-Effectiveness of Minimally Invasive versus Open Transforaminal Lumbar Interbody Fusion for Degenerative Spondylolisthesis Associated Low-Back and Leg Pain Over Two Years

Scott L. Parker1, Owoicho Adogwa1, Ali Bydon2, Joseph Cheng1, Matthew J. McGirt1

Key words
- Cost utility
- Minimally invasive
- Transforaminal lumbar interbody fusion

Abbreviations and Acronyms
CI: Confidence interval
DBM: Demineralized bone matrix
EQ-5D: EuroQol-5D
ICER: Incremental cost effectiveness ratio
IQR: Interguarteile range
MIS: Minimally invasive
ODI: Oswestry Disability Index
QALY: Quality-adjusted life year
TLIF: Transforaminal lumbar interbody fusion
VAS: Visual analog scale

OBJECTIVE: Minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) for lumbar spondylolisthesis allows for surgical treatment of back and leg pain while theoretically minimizing tissue injury and accelerating overall recovery. Although the authors of previous studies have demonstrated shorter length of hospital stay and reduced blood loss with MIS versus open-TLIF, short- and long-term outcomes have been similar. No studies to date have evaluated the comprehensive health care costs associated with TLIF procedures or assessed the cost-utility of MIS- versus open-TLIF. As such, we set out to assess previously unstudied end points of health care cost and cost-utility associated with MIS- versus open-TLIF.

METHODS: Thirty patients undergoing MIS-TLIF (n = 15) or open-TLIF (n = 15) for grade I degenerative spondylolisthesis associated back and leg pain were prospectively studied. Total back-related medical resource use, missed work, and health-state values (quality-adjusted life years [QALYs], calculated from EQ-5D with U.S. valuation) were assessed after two-year follow-up. Two-year resource use was multiplied by unit costs on the basis of Medicare national allowable payment amounts (direct cost) and work-day losses were multiplied by the self-reported gross-of-tax wage rate (indirect cost). Difference in mean total cost per QALY gained for MIS- versus open-TLIF was assessed as incremental cost-effectiveness ratio (ICER: COSTmis – COSTopen/QALYmis – QALYopen).

RESULTS: MIS versus open-TLIF cohorts were similar at baseline. By two years postoperatively, patients undergoing MIS- versus open-TLIF reported similar mean QALYs gained (0.50 vs. 0.41, P = 0.17). Mean total two-year cost of MIS- and open-TLIF was $35,996 and $44,727, respectively. The $8,731 two-year cost savings of MIS- versus open-TLIF did not reach statistical significance (P = 0.18) for this sample size.

CONCLUSIONS: Although our limited sample size prevented statistical significance, MIS- versus open-TLIF was associated with reduced costs over two years while providing equivalent improvement in QALYs. MIS-TLIF allows patients to leave the hospital sooner, achieve narcotic independence sooner, and return to work sooner than open-TLIF. In our experience, MIS- versus open-TLIF is a cost reducing technology in the surgical treatment of medically refractory low-back and leg pain from grade I lumbar spondylolisthesis.

Minimally invasive techniques for transforaminal lumbar interbody fusion (MIS-TLIF) have recently been introduced with the aim of smaller wounds, less tissue trauma, and faster recovery (9, 37). Although the authors of prospective and retrospective cohort studies have demonstrated reduced blood loss and length of hospitalization with MIS- versus open-TLIF, outcomes have consistently been reported as similar when assessed six months and two years postoperatively (6, 28, 33). In fact, for simpler decompressive surgeries such as microdiscectomy, use of tubular re-
tractors for an MIS approach have been shown to be potentially inferior to open surgery (2).

Nevertheless, it is increasingly being recognized that, as the complexity and morbidity of the surgery increases, the potential advantages of an MIS approach may be amplified. Recently, outcomes were compared during the initial months of recovery after MIS versus open-posterior lumbar interbody fusion, a study that demonstrated accelerated improvement in pain and disability scores with MIS at three months despite similar 12-month outcomes (25). Although increasing evidence suggests that advantages of MIS-TLIF may manifest mostly in the early recovery period rather than in long-term outcomes, no investigators to date have examined whether this accelerated recovery with MIS results in a cost benefit. In fact, no cost-utility studies have been conducted to examine the cost effectiveness of MIS- versus open-TLIF. Given the recent interest in increasing health care costs and the proliferation in spinal fusion procedures, such an analysis may prove valuable from a healthcare economics perspective and help guide resource allocation (10, 38).

We performed a two-year, prospective, cost-utility study to compare MIS- versus open-TLIF in patients with medically refractory low-back and leg pain from grade I lumbar spondylolisthesis. We sought to determine whether MIS- versus open-TLIF allowed for accelerated recovery, resulting in less postoperative medical resource use and costs per quality-adjusted life year (QALY) gained.

METHODS

Inclusion Criteria
The primary aim of this study was to prospectively determine whether MIS- versus open-TLIF for grade I spondylolisthesis is a cost-effective advancement in TLIF surgery. All patients underwent TLIF surgery by four surgeons and were prospectively followed at two tertiary academic centers. The institutional review board from each institution approved this study. To be included, a patient had to have: (i) evidence on magnetic resonance imaging of grade I degenerative lumbar spondylolisthesis, (ii) mechanical low-back pain and radicular symptoms, (iii) a nonresponse to at least six weeks of conservative therapy; and (iv) be 18–70 years of age. Patients were excluded if they had: (i) a history of a previous back operation; (ii) an extraspinal cause of back pain or sciatica; (iii) an active medical or workman’s compensation lawsuit; (iv) any pre-existing spinal pathology; or (v) were unwilling or unable to participate with follow-up procedures. Patients with notable associated abnormalities, such as inflammatory arthritis or metabolic bone disease, were also excluded.

For all included patients, each was thought to be appropriate for either MIS- or open-TLIF. MIS- versus open-TLIF was performed purely on the basis of the surgeon’s preference. All open-TLIFs were performed by the same two surgeons who preferred open approaches, whereas all MIS-TLIFs were performed by the same two surgeons who preferred MIS approaches. In addition, the surgeons performing open and MIS-TLIF had nearly identical postoperative treatment paradigms. In all cases, regardless of MIS versus open technique, the surgeon recommended initiation of physical therapy at six weeks postoperatively (when recommended by physical therapy evaluation) and return to work as soon as the patient felt capable.

Fusion was assessed by lateral flexion and extension radiography (31). The diagnosis of symptomatic pseudoarthrosis was made via the following criteria: (i) symmetrical mechanical back pain with radiographic evidence of pathological movement on dynamic films or (ii) haloing or screw loosening on postoperative computed tomography.

Clinical Outcome Measures
Preoperative and two-year postoperative pain, disability, and quality of life were assessed via phone interview by an independent investigator not involved with clinical care. Duration of narcotic use and time to return to work was documented in real time as part of a standard of care protocol and verified by patient during phone interview at two-years postoperatively. Patient-assessed questionnaires included visual analog scale for low back pain (11, 14) and leg pain (14, 17), Oswestry Disability Index (ODI) (7, 8, 32), and EuroQol-5D (EQ-5D) (19, 20) quality of life.

Surgical Technique
MIS-TLIF. Fluoroscopy was used to determine the operative level. The TLIF procedure was performed on the side of radicular symptoms. If both legs were symptomatic, the approach was from the side of more severe pathology and contralateral lamina and foramina decompressed. Sequential soft-tissue dilators were then inserted through the incision down to the facet complex until the desired working diameter was achieved. A facetectomy was then performed with the use of a high-speed drill from lateral to medial to expose the pos-terolateral aspect of the disk. Intradiscal distraction and disk space preparation were performed with the use of standard interbody fusion instruments.

Cartilaginous material was removed from the endplates with an endplate scraper. An interbody graft was then placed anteriorly and contralateral to the annulotomy within the interbody space. Fluoroscopy was used to ensure satisfactory placement of the interbody graft. When necessary, the contralateral ligamentum flavum was resected to expose the contralateral exiting and traversing nerve roots. If needed, the tubular retractor was angled contralaterally so that a more extensive boney decompression could be performed. Once the interbody fusion was carried out, the tubular retractor was removed and four pedicle screws were percutaneously placed immediately above and below the interbody segment to be fused.

Under fluoroscopic guidance, a Jamshidi needle was inserted into the pedicles. A K-wire was then passed through the Jamshidi trocar into the pedicles. With the use of cannulated instruments, a bone tap followed by cannulated screw was advanced over the K-wire. A rod was then placed percutaneously to connect the screws. Compression was applied to the construct before final tightening, providing compression of the bone graft within the middle column, and maximizing lordosis. In all cases, local autogenous bone with or without bone extenders (demineralized bone matrix [DBM]) was used for bone grafting. All wounds were copiously irrigated, and the wounds were closed in layers.

Open-TLIF. A midline skin incision was used. The fascia was incised and the para-vertebral muscles dissected from the spine. Radiographs were used to check the appropriate level. Bilateral pedicle screw-rod constructs were inserted and laminectomy and unilateral facetectomy was then performed at that level, followed by unilateral annu-
Treatment Effectiveness

QALYs, which account for both quality and length of life, are recommended for assessing the value of interventions in health and medicine (13). Two-year change in mean EQ-5D (3, 19) values provided an estimate of QALYs gained for each treatment group. Health-state quality of life values, calculated from EQ-5D with U.S. valuation were prospectively assessed by an independent investigator not involved with clinical care. The patient-assessed EQ-5D quality-of-life questionnaire was completed via phone interview for all patients.

Resource Utilization and Direct Cost

Patient-reported resource use data were collected prospectively via phone interview at two years postoperatively and included outpatient visits (surgeons, chiropractors, other physicians, physical therapists, acupuncturists, or other health care providers); spine-related diagnostic tests (radiograph, computed tomography scan, magnetic resonance imaging, and electromyogram); injections; devices (e.g., braces, canes, walkers, shoe inserts); emergency room visits; and rehabilitation or nursing home days. Participants were asked in detail about their use of all medications, including but not limited to nonsteroidal anti-inflammatory drugs and cyclooxygenase-2 inhibitors, oral steroids, narcotics, muscle relaxants, and antidepressants.

To estimate direct medical cost at each time point, self-reported instances of medical resource use were multiplied by unit costs for each cost component. Unit costs for office visits, hospitalizations, diagnostic tests, and procedures were determined on the basis of current Medicare national allowable payment amounts. Medication prices were based on Redbook prices. Surgery costs depended on whether or not intraoperative complications occurred, which determined the diagnosis-related group. The current Medicare mean total diagnosis-related group price was used to reflect hospital-related surgery costs. Surgeon costs were determined on the basis of current Medicare allowable amounts using the resource-based relative value scale.

Indirect Cost

At each follow-up, productivity losses as a result of spine-related problem (i.e., missed work days for those employed outside of the home and missed homemaking days for those who reported housekeeping as their primary activity) were recorded. Costs were estimated using the standard human capital approach (18) by multiplying the change in hours worked by the gross-of-tax wage rate based on self-reported wages at study entry.

Incremental Cost-Effectiveness Ratio

The primary end point for the cost-effectiveness analysis is the incremental cost-effectiveness ratio (ICER). To estimate the ICER, average total costs and average QALYs from baseline to two years are estimated for both treatment groups. The ICER is defined as the difference in mean total costs between cohorts, divided by the difference in mean QALYs as follows: ICER = \( \frac{\text{Cost}_{\text{mis}} - \text{Cost}_{\text{open}}}{\text{QALY}_{\text{mis}} - \text{QALY}_{\text{open}}} \).

Statistical Analysis

Parametric data were given as mean ± SD and compared via the Student t test. Nonparametric data was given as median (interquartile range) and compared via Mann-Whitney U test. Nominal data was compared via \( \chi^2 \) test. \( P < 0.05 \) was considered statistically significant.

RESULTS

Patient Population

A total of 30 patients were enrolled in the study at two academic centers. There were 17 cases (nine MIS, eight open) performed at one institution and 13 cases (six MIS, seven open) performed at the other, \( P = 1.0 \). All patients were available for follow-up at two years postoperatively. Overall, mean ± SD age was 50 ± 9.6 years (18 women, 12 men). All patients presented with both back and leg pain and radiographic evidence of grade 1 degenerative spondylolisthesis. Interbody fusion was performed at L4-L5 in 19 (63%) patients and L5-S1 in 11 (37%) patients. All cases were one-level fusions. For all patients at presentation, mean back pain-VAS and leg-pain-VAS were 8.86 ± 1.43 and 7.50 ± 2.81, respectively. Preoperative ODI and EQ-5D scores were 34.72 ± 9.84 and 0.36 ± 0.14, respectively. MIS- and open-TLIF cohorts were similar at baseline (Table 1).

Open- versus MIS-TLIF patients were similarly employed in sedentary occupations (9 [60.0%] vs. 7 [46.7%], \( P = 0.72 \)). Median length of surgery (interquartile range [IQR]) was shorter for open- versus MIS-TLIF procedures (210 [150–240] vs. 300 [260–500] minutes, \( P = 0.008 \)). The median [IQR] estimated blood loss during surgery trended higher for open- versus MIS-TLIF procedures (295 [280–350] vs. 200 [175–300] mL, \( P = 0.09 \)). There were no patients who experienced intraoperative durotomy, developed surgical-site infection, incisional cerebrospinal fluid leak, or hardware failure. Bone morphogenetic protein was not used in any patient. Median [IQR] length of hospitalization after surgery was significantly less for MIS- versus open-TLIF (3.0 [2.0–4.0] vs. 5.0 [4.0–6.0] days; \( P = 0.001 \)). No patients developed symptomatic pseudoarthrosis by two years postoperatively, and no patients required revision surgery.

Treatment Effectiveness

Mean preoperative health state values significantly improved by two years postoperatively for both MIS and open-TLIF (Figure 1). Total mean QALYs gained for MIS-TLIF patients was 0.50 (95% confidence interval [95% CI] 0.37–0.63) and 0.41 (95% CI 0.14–0.68) for open-TLIF patients, a difference of 0.09 QALYs gained in favor of MIS-TLIF over two years. There was no statistical difference in two-year cumulative QALY gained between MIS versus open-TLIF (\( P = 0.17 \)).

Cost Analysis

Total two-year mean costs were $35,996 (95% CI $31,448–$40,544) for MIS-TLIF—
treated patients and $44,727 (95% CI $37,809–51,645) for open-TLIF–treated patients (P = 0.18; Table 2). Mean reported number of health care visits did not differ between the treatment groups (MIS: 8 ± 2 vs. open: 7 ± 2, P = 0.66). Approximately one-half of participants reported physical therapy visits (53% MIS vs. 53% open, P = 1.0); chiropractor visits were infrequent (27% MIS vs. 20% open, P = 1.0); and use of acupuncture was reported by only 13% of participants. A trend of decreased utilization of diagnostic imaging (6.0 vs. 8.2 images, P = 0.20) and medication use (177 vs. 336 medication days, P = 0.19) was observed with MIS-TLIF, with use in both groups decreasing over time after surgery. Treatment groups were similar in use of oral steroids (33% MIS vs. 20% open, P = 0.68) but differed significantly in the mean duration of narcotics (MIS: 2.6 weeks vs. open: 6.5 weeks, P = 0.008). Mean time to return to work was accelerated in patients receiving MIS- versus open-TLIF (8.3 vs. 16.3 weeks, P = 0.02). As depicted in Table 2, during the two-year period, indirect costs accounted for a substantial proportion of total costs in both groups (32.8% of cost for MIS-TLIF patients and 41.2% of costs for open-TLIF patients).

When all costs were considered, MIS- versus open-TLIF was associated with a nonsignificant trend of mean two-year cost savings of $8,731 per patient while providing similar QALYs gained (ICER). Two-year cost and utility gained were similar for MIS and open-TLIF.

**DISCUSSION**

In a two-year prospective cohort study, we collected data on medical resource utilization, occupational disability, and health-related quality of life to estimate cost per QALY gained for MIS and open-TLIF in patients with back and leg pain from grade I spondylolisthesis. In this study of 30 patients (15 MIS and 15 open), we observed similar cumulative two-year improvement in overall health state (MIS: 0.50 QALY vs. open: 0.41 QALY, P = 0.17) and reduced overall cost at two years with MIS-versus open-TLIF procedures, although this difference did not reach statistical significance due to our limited sample size.

On the basis of a power analysis, a study population of 60 patients would have yielded a statistically significant cost savings for MIS-TLIF. A study population of 652 patients would be required to demonstrate a statistically significant difference in QALY gained. Mean two-year direct costs, composed of surgical cost, postoperative doctor visits, medications, injections, physical therapy, and diagnostic imaging, were similar for MIS and open-TLIF. The mean duration of missed work was approximately two-fold greater for open-TLIF, and translated into the significant difference in indirect cost ($6,650). These findings suggest that the observed occupational benefits of MIS-TLIF are not trivial from a societal or economical viewpoint. All patients in both cohorts were employed, and none were involved with a disability claim. Both TLF techniques were effective and resulted in significantly improved QALYs during a two-year period.

**Table 1. Characteristics of 30 Patients Undergoing First-Time One-Level TLIF for Grade I Degenerative Spondylolisthesis-Associated Back and Leg Pain**

<table>
<thead>
<tr>
<th></th>
<th>MIS-TLIF n = 15</th>
<th>Open-TLIF n = 15</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>50.8 ± 7.9</td>
<td>49.7 ± 11.4</td>
<td>0.77</td>
</tr>
<tr>
<td>Female</td>
<td>8 (53.3%)</td>
<td>10 (66.7%)</td>
<td>0.71</td>
</tr>
<tr>
<td>L4–5</td>
<td>10 (66.7%)</td>
<td>8 (53.3%)</td>
<td>0.71</td>
</tr>
<tr>
<td>L5–S1</td>
<td>5 (33.3%)</td>
<td>7 (46.7%)</td>
<td>0.71</td>
</tr>
<tr>
<td>Preop VAS-LP</td>
<td>8.5 ± 1.3</td>
<td>8.2 ± 1.3</td>
<td>0.78</td>
</tr>
<tr>
<td>Preop VAS-BP</td>
<td>8.4 ± 1.7</td>
<td>9.3 ± 0.9</td>
<td>0.08</td>
</tr>
<tr>
<td>Preop ODI</td>
<td>36.9 ± 6.3</td>
<td>34.3 ± 11.5</td>
<td>0.32</td>
</tr>
<tr>
<td>Preop EQ-5D</td>
<td>0.42 ± 0.13</td>
<td>0.30 ± 0.14</td>
<td>0.26</td>
</tr>
<tr>
<td>Postop VAS-LP</td>
<td>5.5 ± 2.9</td>
<td>3.5 ± 3.5</td>
<td>0.25</td>
</tr>
<tr>
<td>Postop VAS-BP</td>
<td>5.5 ± 2.6</td>
<td>4.7 ± 3.2</td>
<td>0.49</td>
</tr>
<tr>
<td>Postop ODI</td>
<td>15.7 ± 8.9</td>
<td>17.1 ± 9.5</td>
<td>0.82</td>
</tr>
</tbody>
</table>
| Postop EQ-5D     | 0.92 ± 0.06     | 0.70 ± 0.15      | 0.17    

BP, back pain; EQ-5D, EuroQol-5D; LP, leg pain; ODI, Oswestry Disability Index; Postop, postoperative; Preop, preoperative; TLIF, transforaminal lumbar interbody fusion; VAS, visual analog scale.
The accelerated recovery associated with MIS results in marked long-term improvement in pain, disability, and QOL, our results suggest that MIS results in quicker recovery, manifesting as improvements in work capacity and narcotic independence, factors that carry significant economic and social productivity importance.

These results are consistent with prior studies comparing post-operative outcomes of MIS versus open-TLIF (1, 28). Ntoukas and Müller (25) demonstrated greater pain relief with MIS versus open-posterior lumbar interbody fusion in the perioperative period and three months postoperatively, but outcomes were similar at one year. The indirect costs associated with missed work after TLIF comprised a large percentage of the overall two-year cost (MIS: 32.8%, open: 41.2%) in this study, and was the primary reason for the cost-difference seen between the two cohorts.

Although we are the first study to assess comprehensive two-year costs associated with MIS versus open-TLIF procedures, there are previously published studies that describe costs associated with other types of lumbar spinal fusion. The average total two-year cost for TLIF procedure in this study was $40,362, with direct and indirect components of $25,242 and $15,120, respectively. These figures are comparable with previously published studies in which authors describe costs associated with other types of lumbar fusion for low back and/or leg pain. Kuntz et al (21) compared the cost associated with laminectomy with and without lumbar fusion, and reported a cost of $35,669 for instrumented lumbar laminectomy. A study by Ray (30) reported the direct hospital costs associated with one and two-level 360-degree fusion constructs to be $41,813 and $47,320, respectively. Schofferman et al (34) report direct hospital costs of $38,707 and $44,047 for 270-degree and 360-degree fusion, respectively, consistent with our current cost estimates.

Hacker (15) compared cost associated with posterior lumbar interbody fusion and 360-degree fusion. Mean hospital costs for posterior lumbar interbody fusion and 360-degree fusion were similar at $17,713 and $19,832, respectively; however, postoperative disability pay was significantly greater in the 360-degree fusion cohort ($45,838 vs. $28,643, \( P < 0.0003 \)). Similar to the results of our study, this cost difference was largely the result of indirect cost differences of an earlier return to work. These findings demonstrate the importance of considering indirect costs when one examines the total cost associated with spinal surgery because they may contribute a significant portion of the total cost. In fact, although the direct costs of medical imaging, emergency services, social services, pain medication, physical therapy, caregiver services, and surgical intervention are estimated to range from 20 to 60 billion dollars annually, the marked physical disability, pain, and depression accompanying low-back and leg pain are associated with a trend towards reduced total cost over two years while providing similar improvement in QALYs, suggesting that MIS-TLIF is a cost reducing technology in the surgical treatment of medically refractory low back and leg pain from grade I degenerative spondylolisthesis.

Growing evidence suggests that the advantage of MIS-TLIF may manifest mostly in the early recovery period; however, the current study is the first that examines whether the accelerated recovery associated with MIS results in a cost benefit. Two of the most clinically relevant factors in the perioperative period of lumbar spine surgery are time to narcotic independence and time to return to work. We found that each of these was reduced approximately two-fold by a minimally invasive approach. Although both TLIF techniques resulted in marked long-term improvement in pain, disability, and QOL, our results suggest that MIS-TLIF results in quicker recovery, manifesting as improvements in work capacity and narcotic independence, factors that carry significant economic and social productivity importance.

### Table 2. Mean Costs (95% CIs) by Treatment Received and Type of Cost and Component

<table>
<thead>
<tr>
<th>Component</th>
<th>MIS-TLIF</th>
<th>Open-TLIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgery</td>
<td>$21,000 (21,000–21,000)</td>
<td>$21,933 (20,104–23,761)</td>
</tr>
<tr>
<td>Health care visits</td>
<td>$964 (524–1,403)</td>
<td>$1,169 (582–1,756)</td>
</tr>
<tr>
<td>Surgeon</td>
<td>$299 (219–380)</td>
<td>$264 (203–325)</td>
</tr>
<tr>
<td>Other physician</td>
<td>$238 (31–444)</td>
<td>$189 (45–333)</td>
</tr>
<tr>
<td>Chiropractor</td>
<td>$68 (7–130)</td>
<td>$39 (0–83)</td>
</tr>
<tr>
<td>Physical therapy</td>
<td>$289 (82–495)</td>
<td>$677 (50–1303)</td>
</tr>
<tr>
<td>Acupuncture</td>
<td>$70 (7–134)</td>
<td>$0 (0–0)</td>
</tr>
<tr>
<td>Diagnostic imaging</td>
<td>$1,499 (1,083–1,915)</td>
<td>$1,716 (885–2,547)</td>
</tr>
<tr>
<td>MRI</td>
<td>$708 (376–1040)</td>
<td>$482 (214–750)</td>
</tr>
<tr>
<td>Radiograph</td>
<td>$104 (63–146)</td>
<td>$255 (207–304)</td>
</tr>
<tr>
<td>CT</td>
<td>$542 (348–735)</td>
<td>$406 (325–488)</td>
</tr>
<tr>
<td>EMG</td>
<td>$127 (46–209)</td>
<td>$85 (25–145)</td>
</tr>
<tr>
<td>ER visits</td>
<td>$18 (0–52)</td>
<td>$12 (0–27)</td>
</tr>
<tr>
<td>Rehab</td>
<td>$0 (0–0)</td>
<td>$476 (0–1113)</td>
</tr>
<tr>
<td>Medications, injections</td>
<td>$738 (176–1,300)</td>
<td>$1,463 (763–2,162)</td>
</tr>
<tr>
<td>NSAID</td>
<td>$297 (0–691)</td>
<td>$791 (270–1311)</td>
</tr>
<tr>
<td>Oral steroids</td>
<td>$35 (7–63)</td>
<td>$28 (0–60)</td>
</tr>
<tr>
<td>Narcotics</td>
<td>$97 (62–132)</td>
<td>$245 (153–338)</td>
</tr>
<tr>
<td>Muscle relaxants</td>
<td>$62 (18–107)</td>
<td>$214 (0–446)</td>
</tr>
<tr>
<td>Antidepressants</td>
<td>$189 (0–387)</td>
<td>$152 (0–399)</td>
</tr>
<tr>
<td>Injections</td>
<td>$58 (0–138)</td>
<td>$33 (0–97)</td>
</tr>
<tr>
<td>Total direct costs</td>
<td>$24,201 (23,099–25,303)</td>
<td>$26,282 (24,618–27,946)</td>
</tr>
<tr>
<td>Missed work</td>
<td>$11,795 (7,405–16,185)</td>
<td>$18,445 (11,745–25,145)</td>
</tr>
<tr>
<td>Total indirect costs</td>
<td>$11,795 (7,405–16,185)</td>
<td>$18,445 (11,745–25,145)</td>
</tr>
<tr>
<td>Total costs</td>
<td>$35,996 (31,448–40,544)</td>
<td>$44,727 (37,809–51,645)</td>
</tr>
</tbody>
</table>
pain has resulted in a much greater indirect cost of lost work and decreased social productivity, estimated to range from $50-100 billion dollars annually (4, 5, 22, 23, 26).

The limitations inherent in our study have implications for its interpretation. First, the limited sample size precluded the differences seen from reaching statistical significance, introducing the possibility of type 2 error. Although patients in the MIS and open-TLIF cohorts were prospectively followed and matched at baseline, bias associated with nonrandomization cannot be discounted. All patients in the study had grade I degenerative spondylolisthesis, did not respond to medical management, and were considered to be appropriate for either MIS- or open-TLIF.

Nevertheless, differences in surgeon technique may have contributed to differences in outcome. Complications have been shown to markedly affect cost of care. For surgeons early in their MIS learning curve, costs of MIS may be greater than those assessed here. Practices with varying efficacy and complications will undoubtedly have different costs and effectiveness ratios that will evolve over the course of one’s learning curve, with respect to both technical skills and patient selection. Furthermore, although outcome assessments were made by an independent phone interviewer not involved with patient care, patients were not blinded to treatment group. It remains unknown how self-knowledge of MIS may affect patient reported outcomes.

However, we do believe that the “real-world” practice setting associated with the comparative effectiveness study design carries benefits not allowed in controlled trials. Patient follow-up, adjuvant treatments after surgery, two-year follow-up testing, and various resources contributing to cost were not controlled, which allowed us an accurate comparison of the comprehensive postoperative care of these patients. Also, the results of this study may not apply to practices with greater complication rates or less efficacy of surgery. Nevertheless, prospective-randomized trials remain the gold standard and should be performed to corroborate the results observed here.

CONCLUSIONS
Although our limited sample size prevented statistical significance, MIS- versus open-TLIF was associated with reduced costs over two years while providing equivalent improvement in QALYs. MIS-TLIF allows patients to leave the hospital sooner, achieve narcotic independence sooner, and return to work sooner than open-TLIF. In our experience, MIS vs. open-TLIF is a cost reducing technology in the surgical treatment of medically refractory low-back and leg pain from grade I lumbar spondylolisthesis.

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