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A Comparison of Minimally Invasive and Open Transforaminal Lumbar Interbody Fusion for Grade 1 Degenerative Lumbar Spondylolisthesis: An Analysis of the Prospective Quality Outcomes Database

BACKGROUND: It remains unclear if minimally invasive transforaminal lumbar interbody fusion (MI-TLIF) is comparable to traditional, open TLIF because of the limitations of the prior small-sample-size, single-center studies reporting comparative effectiveness.

OBJECTIVE: To compare MI-TLIF to traditional, open TLIF for grade 1 degenerative lumbar spondylolisthesis in the largest study to date by sample size.

METHODS: We utilized the prospective Quality Outcomes Database registry and queried patients with grade 1 degenerative lumbar spondylolisthesis who underwent single-segment surgery with MI- or open TLIF methods. Outcomes were compared 24 mo postoperatively.

RESULTS: A total of 297 patients were included: 72 (24.2%) MI-TLIF and 225 (75.8%) open TLIF. MI-TLIF surgeries had lower mean body mass indexes (29.5 $\pm$ 5.1 vs 31.3 $\pm$ 7.0, $P = .0497$) and more worker's compensation cases (11.1% vs 1.3%, $P < .001$) but were otherwise similar. MI-TLIF had less blood loss (108.8 $\pm$ 85.6 vs 299.6 $\pm$ 242.2 mL, $P < .001$), longer operations (228.2 $\pm$ 111.5 vs 189.6 $\pm$ 66.5 min, $P < .001$), and a higher return-to-work (RTW) rate (100% vs 80%, $P = .02$). Both cohorts improved significantly from baseline for 24-mo Oswestry Disability Index (ODI), Numeric Rating Scale back pain (NRS-BP), NRS leg pain (NRS-LP), and Euro-Qol-5 dimension (EQ-5D) ($P > .001$). In multivariable adjusted analyses, MI-TLIF was associated with lower ODI ($\beta = -4.7$; 95% CI $= -9.3$ to -0.04; $P = .048$), higher EQ-5D ($\beta = 0.06$; 95% CI = 0.01-0.11; $P = .02$), and higher satisfaction (odds ratio for North American Spine Society [NASS] 1/2 = 3.9; 95% CI = 1.4-14.3; $P = .02$). Though trends favoring MI-TLIF were evident for NRS-BP ($P = .06$), NRS-LP ($P = .07$), and reoperation rate ($P = .13$), these results did not reach statistical significance.

CONCLUSION: For single-level grade 1 degenerative lumbar spondylolisthesis, MI-TLIF was associated with less disability, higher quality of life, and higher patient satisfaction compared with traditional, open TLIF. MI-TLIF was associated with higher rates of RTW, less blood loss, but longer operative times. Though we utilized multivariable adjusted analyses, these findings may be susceptible to selection bias.

KEY WORDS: Quality Outcomes Database, Lumbar spondylolisthesis, Transforaminal lumbar interbody fusion, Minimally invasive surgery, Lumbar stenosis, Lumbar spondylosis

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ABBREVIATIONS: EQ-5D, Euro-Qol-5 dimension; **MI-TLIF,** minimally invasive transforaminal lumbar interbody fusion; **NASS,** North American Spine Society; **NRS-BP,** Numeric Rating Scale back pain; **NRS-LP,** Numeric Rating Scale leg pain; **ODI,** Oswestry Disability Index; **QOD,** Quality Outcomes Database; **RTW,** return to work

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The transforaminal lumbar interbody fusion (TLIF) procedure—first described in 1982[1]—has long been applied as a treatment for degenerative lumbar spondylolisthesis. Despite its advantages compared to the traditional posterior lumbar interbody fusion,[2,3] disadvantages include the extensive soft tissue dissection required for the traditional, open TLIF.[4] To mitigate this disadvantage, Foley and Lefkowitz[5] described a minimally invasive approach (MI-TLIF) that limited the incision size and extent of soft tissue dissection, in turn potentially expediting postoperative recovery. Despite these potential advantages, it remains unclear if MI-TLIF is comparable to traditional, open TLIF with regard to long-term clinical outcomes following surgery because of the limitations of the prior small sample size, single-center studies reporting comparative effectiveness.[6-13]

To this end, we compared patients with symptomatic single-level grade 1 degenerative lumbar spondylolisthesis who underwent MI-TLIF to those who underwent traditional, open TLIF using a multicenter, multidisciplinary prospective registry in the United States.

METHODS

Data Source

This study utilized data from the Quality Outcomes Database (QOD) Spondylolisthesis Study Group,[14-23] comprising 12 of the highest-enrolling centers within the multidisciplinary QOD prospective registry. The primary aim of the study group is to determine the comparative effectiveness of decompression alone vs fusion surgery for Meyerding[24] grade 1 degenerative lumbar spondylolisthesis.[16]

Patient Inclusion

Enrolled patients underwent single-segment surgery for grade 1 degenerative lumbar spondylolisthesis from July 1, 2014, through June 30, 2016. Attending spine surgeons at each participating site reviewed preoperative plain films (standing neutral or dynamic) to confirm the diagnosis of grade 1 spondylolisthesis. In addition to standard QOD inclusion and exclusion criteria (which have been published previously[25-27]), all patients were included who underwent a TLIF via either a MI or open approach. MI-TLIF was defined as a procedure having an interbody device placed using a tubular retractor via a Wiltse plane approach and pedicle screw placement via a percutaneous technique. Exclusion criteria included (1) higher than grade 1 spondylolisthesis, (2) partially MI-TLIF (eg, mini-open), and (3) 2-stage procedures. Institutional review board approval was obtained (University of California, San Francisco, IRB 16-20085).

Demographic, Clinical, and Surgical Variables

Demographic, clinical, and surgical variables were collected. Baseline PRO scores were collected for Oswestry Disability Index (ODI) score, Numeric Rating Scale (NRS) back pain (NRS-BP), NRS leg pain (NRS-LP), and Euro-Qol-5 dimension (EQ-5D) questionnaire.

Primary and Secondary Outcomes

We assessed primary and secondary outcomes at 24 mo using validated questionnaires. The primary outcome of interest was ODI (range, 0-100, with higher scores indicating more disability related to BP[28]).

The secondary outcomes included NRS-BP (range, 0-10, with higher scores indicating more BP disability[29]), NRS-LP (range, 0-10, with higher scores indicating more LP disability[29]), EQ-5D (range, 0-1, with scores relaying a preference-based quality-of-life outcome metric and higher scores indicating less disability[30]), and North American Spine Society (NASS) satisfaction questionnaire (range, 1-4, with lower scores indicating more satisfaction with surgery[31]). For NASS satisfaction, patient satisfaction was gauged by a single item scored 1 through 4, denoting the following responses respectively: surgery met my expectations; I did not improve as much as I had hoped, but I would undergo the same operation for the same results; surgery helped but I would not undergo the same operation for the same results; and I am the same or worse as compared to before surgery. Additionally, 3-mo readmission, cumulative 24-mo reoperation, cumulative 24-mo return-to-work (RTW) rates, 30-d complication rates, and 24-mo radiological outcomes (reduction of listhesis and radiographic fusion) are reported and compared. Reported complications included within the QOD dataset include 30-d (1) deep venous thrombosis/pulmonary embolism, (2) new motor deficit, (3) myocardial infarction, (4) urinary tract infection, (5) surgical site infection, (6) postoperative hematoma, (7) cerebrovascular accident, (8) durotomy, and (9) pneumonia. QOD complication data were audited and verified by each participating site. Radiological measurements and adjudication of radiographic fusion were evaluated from baseline and 24-mo plain radiographs and were performed by a single neuroradiologist not affiliated with the study group.

Statistical Analysis

Univariate analyses utilized a paired *t*-test, 2-sampled *t*-test, and Pearson's chi-square with Yates' correction for continuity when appropriate. For 2 × 2 categorical tests in which a cell had an expected frequency below 1, Fisher's exact test was utilized. Multivariable regression models were constructed to assess the impact of MI-TLIF on PROs. Each model adjusted for demographic, clinical, surgical, and socioeconomic variables reaching $P < .20$ on univariate comparisons between open and MI-TLIF cohorts. Additionally, each PRO model adjusted for each respective baseline PRO value. For NASS satisfaction, a logistic regression model was constructed, comparing NASS 1 and 2 (ie, those who would undergo surgery again) vs NASS 3 and 4 groupings (ie, those who would not undergo surgery again), again adjusting for variables reaching $P < .20$ on univariate comparisons between the open and MI-TLIF cohorts. R 2.15.2 (R: A language and environment for

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TABLE 1. Characteristics of Patients Undergoing Surgery for Grade 1 Lumbar Spondylolisthesis

	MI-TLIF (n = 72)	Open TLIF (n = 225)	*P* value
Age (yr), mean ± SD	62.1 ± 10.6	59.5 ± 11.7	.10
Female, n (%)	40 (55.6)	143 (63.6)	.22
BMI, mean ± SD	29.5 ± 5.1	31.3 ± 7.0	.0497[a]
Smoker, n (%)	9 (12.5)	32 (14.2)	.71
Comorbidities, n (%)			
Diabetes mellitus	7 (9.7)	34 (15.1)	.25
Coronary artery disease	9 (12.5)	24 (10.7)	.67
Anxiety	11 (15.3)	46 (20.4)	.33
Depression	16 (22.2)	56 (24.9)	.65
Osteoporosis	3 (4.2)	14 (6.2)	.72
mm of listhesis, mean ± SD	5.9 ± 3.4	6.5 ± 3.2	.42
Dynamic instability at baseline, n (%)	11 (of 32) (34.4)	24 (of 78) (30.8)	.71
Dominant presenting symptom, n (%)			.54
Back pain dominant	33 (45.8)	88 (39.1)	
Leg pain dominant	10 (13.9)	30 (13.3)	
Back pain = leg pain	29 (40.3)	107 (47.6)	
Motor deficit present at presentation, n (%)	4 (5.6)	53 (23.6)	<.001[a]
Independently ambulatory, n (%)	64 (88.9)	208 (92.4)	.34
Symptom duration, n (%)			.34
<3 mo	0 (0)	5 (2.2)	
>3 mo	69 (95.8)	211 (93.8)	
ASA grade, n (%)			.59
1 or 2	42 (58.3)	126 (56.0)	
3 or 4	26 (36.1)	91 (40.4)	
Ethnicity, n (%)			
Hispanic or Latino	5 (6.9)	9 (3.5)	.48
Education level, n (%)			
4 yr of college education or more	29 (40.3)	75 (33.3)	.28
Employment status, n (%)			
Employed or employed and on leave	39 (54.2)	108 (48.0)	.36
Private insurance, n (%)	47 (65.3)	118 (52.4)	.06
Use of worker's compensation, n (%)	8 (11.1)	3 (1.3)	<.001[a]
ODI, baseline, mean ± SD	46.2 ± 16.3	48.0 ± 16.6	.41
NRS back pain, baseline, mean ± SD	6.9 ± 2.6	7.0 ± 2.3	.70
NRS leg pain, baseline, mean ± SD	6.3 ± 2.8	6.6 ± 2.8	.41
EQ-5D, baseline, mean ± SD	0.58 ± 0.20	0.53 ± 0.22	.08
>2-yr follow-up rate, n (%)	60 (83.3)	196 (87.1)	.42

ASA, American Society of Anesthesiologists; BMI, body mass index; EQ-5D, EuroQol-5D; MI, minimally invasive surgery; NRS, Numeric Rating Scale; ODI, Oswestry Disability Index; TLIF, transforaminal lumbar interbody fusion.
Values do not add up to 100%, in which there is missing data.
[a]Denotes a significant difference with *P* value < .05.

statistical computing; R Foundation for Statistical Computing, Vienna, Austria) was utilized for statistical analyses. The "miss Forest" R package was used to impute missing data. An alpha of 0.05 for considered statistically significant, and *P* values were 2 tailed.

RESULTS

A total of 297 patients were included: 72 MI-TLIF (24.2%) and 225 open TLIF (75.8%). Follow-up rates at 24 mo were similar between the cohorts (MI-TLIF 83.3% vs open TLIF 87.1%, $P = .42$). Table 1 includes baseline demographic and clinical variables for the 2 cohorts. The average ages were similar (MI-TLIF 62.1 vs open TLIF 59.5 yr, $P = .10$). The MI-TLIF cohort had lower rates of motor deficit at baseline (5.6% vs 23.6%, $P < .001$), lower mean body mass index (29.5 ± 5.1 vs 31.3 ± 7.0, $P = .0497$), and a higher proportion of worker's compensation cases (11.1% vs 1.3%, $P < .001$). Patients did not differ significantly at baseline for ODI, NRS-BP, NRS-LP, and EQ-5D (all $P > .05$).

Table 2 compares perioperative parameters for the MI-TLIF and open TLIF cohorts. Perioperatively, MI-TLIF was associated with less blood loss (108.8 ± 85.6 vs 299.6 ± 242.2 mL,

TABLE 2. Hospital Data for Patients Undergoing Surgery for Grade 1 Lumbar Spondylolisthesis

	MI-TLIF (n = 72)	Open TLIF (n = 225)	*P* value
Estimated blood loss (mL), mean ± SD	108.8 ± 85.6	299.6 ± 242.2	<.001[a]
Operative time (min), mean ± SD	228.2 ± 111.5	189.6 ± 66.5	<.001[a]
Length of hospitalization (d), mean ± SD	2.9 ± 1.8	3.3 ± 1.6	.08
Discharge disposition			.60
Home or home health care, n (%)	67 (93.1)	205 (91.1)	
Complications, 30 d, n (%)	5 (6.9)	17 (7.6)	.86

MI-TLIF, minimally invasive transforaminal lumbar interbody fusion.
[a]Denotes a significant difference with *P* value < .05.

TABLE 3. Long-Term Outcomes for Patients Undergoing Surgery for Grade 1 Lumbar Spondylolisthesis

	MI-TLIF (n = 72)			Open TLIF (n = 225)		
	Baseline	24 mo	*P* value	Baseline	24 mo	*P* value
ODI, mean ± SD	46.2 ± 16.3	14.3 ± 17.2	<.001[a]	48.0 ± 16.6	24.0 ± 19.8	<.001[a]
NRS back pain, mean ± SD	6.9 ± 2.6	2.3 ± 2.9	<.001[a]	7.0 ± 2.3	3.5 ± 2.9	<.001[a]
NRS leg pain, mean ± SD	6.3 ± 2.8	1.6 ± 2.7	<.001[a]	6.6 ± 2.8	2.8 ± 3.2	<.001[a]
EQ-5D, mean ± SD	0.58 ± 0.20	0.84 ± 0.17	<.001[a]	0.53 ± 0.22	0.74 ± 0.22	<.001[a]

EQ-5D, EuroQol-5; MI-TLIF, minimally invasive transforaminal lumbar interbody fusion; NRS, Numeric Rating Scale; ODI, Oswestry Disability Index.
[a]Denotes a significant difference with *P* value < .05.

P < .001), longer operations (228.2 ± 111.5 vs 189.6 ± 66.5 min, *P* < .001), and a trend toward decreased length of hospitalization (2.9 ± 1.8 vs 3.3 ± 1.6 d, *P* = .08). Discharge disposition to home or home health care was similar (93.1% vs 91.1%, *P* = .60). There were a similar percentage of complications within 30 d (6.9% vs 7.6%, *P* = .86). For the MI-TLIF cohort, 5 patients (6.9%) had complications within 30 d: 2 intraoperative durotomies, 1 new neurological deficit, 1 hematoma, and 1 myocardial infarction. For the open TLIF cohort, there were 18 complications [in 17 patients (7.6%)], including 7 durotomies, 5 surgical site infections, 3 new neurological deficits postoperatively, 2 urinary tract infections, and 1 myocardial infarction.

Both cohorts improved significantly from baseline for 24-mo ODI, NRS-BP, NRS-LP, and EQ-5D (*P* < .001, all comparisons; Table 3).

Table 4 demonstrates the (1) treatment effects for ODI, NRS-BP, NRS-LP, and EQ-5D; (2) NASS satisfaction; (3) readmission rate; (4) reoperation rate; (5) radiographic fusion; and (6) reduction in listhesis (in mm). A significantly higher proportion of MI-TLIF patients were able to RTW 24 mo following surgery (100% vs 80%, *P* = .02) for those eligible (ie, those employed or employed and on leave at baseline). Similarly, there was a trend for fewer reoperations following MI-TLIF, though this did not reach statistical significance (1.4% vs 7.1%, *P* = .13). Table 5 indicates the levels and reasons for reoperation, by cohort.

Multivariable Analysis

In adjusted multivariable analyses, MI-TLIF—compared to open TLIF—was associated with lower ODI (β −4.7; 95% CI = −9.3 to −0.04; *P* = .048), higher EQ-5D (β 0.06; 95% CI = 0.01-0.11; *P* = .02), and higher satisfaction (odds ratio for NASS 1/2 vs 3/4 = 3.9; 95% CI = 1.4-14.3, *P* = .02). Though trends for less BP and less LP were observed for MI-TLIF, they did not reach statistical significance (NRS-BP *P* = .06 and NRS-LP *P* = .07). Table 6 demonstrates the results of the multivariable analyses. **Table, Supplemental Digital Content** reports a sensitivity analysis utilizing complete case analysis.

DISCUSSION

We offer the largest single-study cohort by sample size[6,9-13,32] and a contemporaneous comparison of outcomes following open and MI-TLIF. Given the relative infancy of MI-TLIF and the learning curve associated with the adoption of such procedures,[33] it may be a concern that the initial studies reporting outcomes following MI-TLIF may not reflect the current "real-world" state of MI-TLIF in the United States. In our analysis of 297 patients

TABLE 4. Comparison of Outcomes for Patients Undergoing MI-TLIF vs Open TLIF for Grade 1 Lumbar Spondylolisthesis

	MI-TLIF (n = 72)	Open TLIF (n = 225)	*P* value
ODI, change, mean ± SD	−30.3 ± 20.7	−23.8 ± 19.0	.02[a]
NRS back pain, change, mean ± SD	−4.7 ± 3.2	−3.7 ± 2.9	.03[a]
NRS leg pain, change, mean ± SD	−4.5 ± 3.9	−3.7 ± 3.9	.22
EQ-5D, change, mean ± SD	+0.26 ± 0.22	+0.20 ± 0.23	.09
NASS satisfaction, n (%)	n = 59	n = 192	.17
1	42 (71.2)	120 (62.5)	
2	13 (22.0)	36 (18.8)	
3	1 (1.4)	14 (7.3)	
4	3 (4.2)	22 (11.5)	
Readmissions, 3 mo, n (%)	2 (2.8)	8 (3.6)	.96
Reoperations, 24-mo follow-up, n (%)	1 (1.4)	16 (7.1)	.13
Radiographic parameters			
Radiographic fusion, 24-mo follow-up, n (%)	72 (100)	217 (96.4)	.21
Reduction in listhesis, change in mm, mean ± SD	−2.8 ± 3.8	−2.3 ± 3.5	.51

EQ-5D, EuroQol-5D; MI-TLIF, minimally invasive transforaminal lumbar interbody fusion; NASS, North American Spine Society; NRS, Numeric Rating Scale; ODI, Oswestry Disability Index.
[a]Denotes a significant difference with *P* value < .05.

TABLE 5. Levels and Reasons for Reoperation, by Cohort

	MI-TLIF (n = 72)	Open TLIF (n = 225)	*P* value
Any related reoperation	1 (1.4%)	16 (7.1%) 16 patients with 17 reoperations	.13
Adjacent segment disease requiring extension of fusion	1 (1.4%)	6 (2.7%)	
Surgical site infection	0 (0%)	6 (2.7%)[a]	
Implant removal/revision	0 (0%)	4 (1.8%) (2 for cage repositioning, 1 screw repositioning, 1 removal of painful hardware)	
Pseudoarthrosis	0 (0%)	1 (0.4%)[b]	

MI-TLIF, minimally invasive transforaminal lumbar interbody fusion.
[a]Two of the cases were associated with durotomies and pseudomeningocele formation.
[b]Pseudoarthrosis after single-segment TLIF requiring removal of hardware and anterior lumbar interbody fusion at the index level.

TABLE 6. Effect of MI-TLIF—Compared to Open TLIF—on 24-Month Outcomes Following Surgery for Grade 1 Lumbar Spondylolisthesis

	Adjusted[a] β coefficients (95% CI)	*P* value
ODI, 24 mo	−4.7 (−9.3 to −0.04)	.048[c]
NRS back pain, 24 mo	−0.7 (−1.4 to 0.04)	.06
NRS leg pain, 24 mo	−0.7 (−1.5 to 0.1)	.07
EQ-5D, 24 mo	+0.06 (+0.01 to + 0.11)	.02[c]
	Adjusted[a] odds ratio (95% CI)	
NASS satisfaction[2,b], 24 mo	3.9 (1.4-14.3)	.02[c]

BMI, body mass index; EQ-5D, EuroQol-5D; MI-TLIF, minimally invasive transforaminal lumbar interbody fusion; NASS, North American Spine Society; NRS, Numerical Rating Scale; ODI, Oswestry Disability Index.
β Coefficients are reported such that a negative value for ODI, NRS-BP, and NRS-LP and a positive value for EQ-5D representmore favorable outcomes at 24 mo. Odds ratios (OR) are reported such that an OR >1.0 for NASS satisfaction represents greater satisfaction at 24 mo.
[a]Multivariable models adjusted for demographic, clinical, surgical, and socioeconomic factors with *P* < .20 on univariate comparisons between open and MI-TLIF cohorts: continuous variables (age, BMI, and baseline EQ-5D) and categorical variables (use of private insurance, presence of a motor deficit at baseline, use of workers' compensation, active employment or employed and on leave at baseline, and whether the procedure was an MI surgery or open TLIF). ODI, NRS-BP, NRS-LP, and EQ-5D were also adjusted for their respective baseline PRO value.
[b]OR >1.0 represents an increased odds of greater satisfaction (NASS 1 or 2 relative to 3 or 4) following surgery.
[c]Denotes a significant difference with *P* value < .05.

undergoing TLIF for grade 1 degenerative lumbar spondylolisthesis, we found that MI-TLIF was associated with less disability, higher quality of life, and higher satisfaction compared to traditional, open TLIF. Additionally, near-significant trends for less BP and less LP were evident for MI-TLIF. Perioperatively, MI-TLIF was associated with less blood loss but longer operative times. MI-TLIF was associated with a higher rate of RTW. Additionally, though this did not reach statistical significance, MI-TLIF was associated with a 5-fold lower rate of reoperation compared to traditional open, TLIF.

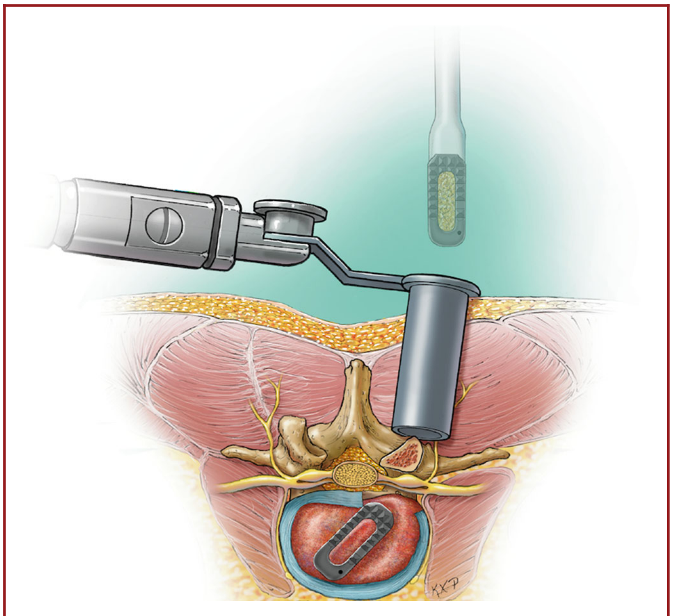

FIGURE. *Illustration demonstrating a typical MI-TLIF approach to interbody placement via the Wiltse plane.*

The open TLIF technique[1] involves a midline approach with extensive dissection of the paraspinous musculature in order to expose the spinous processes, lamina, and facets. This open exposure leads to increased pain and blood loss[34-36] avoided with the advent of the MI-TLIF. The MI approach[5] via the Wiltse plane (Figure) minimizes muscle stripping, muscle retraction, and tissue injury.[37,38] Despite these advantages, potential disadvantages include inferior radiographic outcomes for slip reduction and lumbar sagittal balance,[32] a learning curve for those newly adopting the technique, and longer X-ray exposure time[12] (if fluoroscopy is utilized for MI-TLIF).

Prior investigations have arrived at somewhat differing conclusions regarding the comparative effectiveness of MI vs open TLIF with regard to patient-reported outcomes. Individual studies generally demonstrate equivalency in PROs following surgery,[6,9-12] though Wu et al[13] demonstrated superior 2-yr pain outcomes following MI-TLIF, compared to open TLIF. In a meta-analysis[39] including the aforementioned studies, however, pooled outcomes demonstrated lower ODI following MI-TLIF, compared to open TLIF. Taken together, these results suggest that the prior studies were underpowered. Indeed, our sample size of 297 patients is the largest to date by sample size, permitting the detection of between group differences in the cohort. Here, in addition to lower long-term ODI following surgery for MI-TLIF, we additionally find an association with higher quality of life and satisfaction. These data suggest that for patients in which MI techniques may be appropriate, that MI-TLIF—compared to open TLIF—is at least comparable if not favorable for long-term disability, quality of life, and patient satisfaction. Future larger, multicenter efforts should further clarify our near-significant findings for BP and LP.

In our study, MI-TLIF was associated with significantly longer operative times. This is important to note as the prior literature has been somewhat mixed with some studies reporting longer,[13] similar,[10-12] and shorter[40] operative times for MI-TLIF. Initially, these differences were attributed to the learning curve associated with MI-TLIF and the different pathologies to which TLIF may be applied (eg, lumbar stenosis, spondylolisthesis, infection, pseudarthrosis, or tumor). However, our study demonstrates that in a "real-world" registry of high-volume spine practices in the United States, MI-TLIF remains the longer operation when applied to degenerative spondylolisthesis surgery. This is a potential surrogate for the more technically demanding nature of spondylolisthesis surgery, which requires decompression, screw placement, and reduction of a dislocated vertebral body under a limited surgical corridor. However, with the growing use of navigation for MI-TLIF (and open TLIF), these results may also change.[13] Though the data were presently unavailable, future study may investigate the impact of surgeon experience with each type of procedure (eg, individual learning curve) on outcomes.

The present study also demonstrates findings consistent with the meta-analysis by Qin et al,[39] revealing similar complication rates and reoperation rates between the 2 groups. Of note, the complication profiles also vary similarly, with open TLIF having a higher risk of surgical site infection than MI-TLIF.

Our study demonstrates similar lengths of stay between the 2 cohorts, inconsistent with prior investigations that have found a decreased length of stay for MI-TLIF.[6,8,11-13,39] However, this may be due to the different practice patterns across the different countries studied,[10-13] underscored by the overall longer lengths of stay reported across both procedures in prior comparative studies[6,8,10-13] (range of mean stay for MI-TLIF 1.9-8.4 d and range of mean stay for open TLIF 4.12-14.6 d) compared to the present study (mean 2.9 and 3.3 d for MI-TLIF and open TLIF, respectively). Indeed, the impact of local practice patterns on outcomes such as operative time and length of stay should not be underestimated. For example, not all sites have a scheduled pre-admission encounter focused on social support and anticipated barriers to discharge to decrease length of stay for patients. Future study should further refine the impact of these local practice variations on outcomes, especially if they are inconsistently applied to open and MI patients.

Several radiological outcomes are of interest following lumbar fusion for degenerative lumbar spondylolisthesis, achieving radiographic fusion and reducing the degree of spondylolisthesis. For the former, a concern underlying MI surgery involves the decreased ability to perform intertransverse process and posterolateral arthrodesis for fusion, as in traditional, open techniques. However, we demonstrate similar fusion rates for both cohorts (100% vs 96.4% for MI-TLIF and open TLIF, respectively) (consistent with prior study[39]), suggesting that the primary reliance on interbody fusion is sufficient in MI-TLIF. For the latter, some prior reports have suggested that MI-TLIF is less conductive to reduction in listhesis.[32] However, we did not find evidence to support this claim, as both groups demonstrated similar magnitudes of listhesis reduction. This suggests that if careful technique is applied, MI-TLIF should not be considered an impediment to spondylolisthesis reduction.

Limitations

Despite use of prospective registry data, there remains inherent bias associated with a retrospective analysis. As a prospective registry effort, spinal surgeons selected the procedure (MI-TLIF vs open TLIF) that they deemed was most appropriate for a given patient. Therefore, systematic baseline differences between the cohorts could not be controlled for in a randomized fashion (ie, selection bias). Nonetheless, we utilized multivariable regression methods to correct for a number of important differences between the cohorts. Next, we utilized a fairly narrow, previously described[41] definition of MI-TLIF—specifically requiring the use of percutaneous pedicle screw placement—in order to ensure a more homogeneous cohort (eg, avoiding inclusion of mini-open procedures). It is important to note that "minimally invasive" is a term that may be applied to surgeries on a spectrum, and therefore, interpretation of this work should be in the context of our inclusion criteria. Thirdly, the MI-TLIF may not be appropriate for all patients. As our data suggest, it may not be applicable for the morbidly obese (because of issues with depth limitations for MI surgery instrumentation). Fourth, future study should compare additional surgical (eg, type of bone graft material used) and radiographic parameters (eg, slip angle, facet angle, and disc height) with outcomes. Specifically, the type of intraoperative imaging utilized for MI-TLIF (ie, fluoroscopic vs computed tomographic image guidance) may affect the operative times for MI-TLIF, and a future study may investigate these subgroups separately. Additionally, though we report whether patients returned to work at latest follow-up, the type of occupation and whether patients required modification of their duty was not recorded. Such considerations will be important to delineate when comparing the 2 procedures. Lastly, important factors not studied include surgical costs and the interaction between improved pain outcomes and decreased opioid use. This should be studied in future investigations in light of the opioid drug abuse problem in the United States.

CONCLUSION

For symptomatic, single-level grade 1 degenerative lumbar spondylolisthesis—compared with traditional, open TLIF—MI-TLIF was associated with less disability, higher quality of life, and higher satisfaction. MI-TLIF was associated with higher rates of RTW and significantly less blood loss but longer operative times. Our findings suggest that in well-selected patients, MI-TLIF is at least comparable—if not favorable—to traditional, open TLIF for grade 1 degenerative lumbar spondylolisthesis.

Disclosures

Dr Chan received research support for nonrelated study from Orthofix Medical, Inc. Dr Bisson is a consultant for nView. Dr Foley is a consultant for, holds direct stock ownership in, and is a patent holder with Medtronic; holds direct stock ownership in NuVasive; and holds direct stock ownership in Spine Wave. Dr Glassman is an employee of Norton Healthcare; is a patent holder with, is a consultant for, and received royalties from Medtronic; NuVasive provides funds directly to the database company, no funds are paid directly to individual or institution; and is a past president of the Scoliosis Research Society. Dr Shaffrey holds direct stock ownership in, is a consultant for, and is a patent holder with NuVasive; is a consultant for Zimmer Biomet; and is a patent holder with Medtronic and Zimmer Biomet. Dr Wang is patent holder and has received royalties from DePuy Synthes Spine Inc; is a consultant for DePuy Synthes Spine, JoiMax USA, K2M, and Aesculap Spine; is on the medical advisory board of Vallum; holds direct stock ownership in Spinicity; and has received grants from the Department of Defense. Dr Park is a consultant for and has received royalties from Globus; and is a consultant for NuVasive, Allosource, and Medtronic. Dr Coric is a consultant for and holds direct stock ownership in Spine Wave and Premia Spine; is a consultant for Stryker and Medtronic; and holds direct stock ownership in Spinal Kinetics. Dr Knightly is on the NPA board of directors. Dr Fu is a consultant for SI-BONE. Dr Slotkin is a consultant for Stryker Spine. Dr Virk is a consultant for DePuy Synthes Spine Inc, Globus, and BrainLab Inc; and has received honorarium from DePuy Synthes Spine Inc, Globus, and BrainLab Inc. Dr Haid is a consultant for and has received royalties from NuVasive; holds ownership interest in Spine Universe; and has received royalties from Medtronic Sofamor Danek. Dr Mummaneni is a consultant for DePuy Spine, Globus, and Stryker; holds direct stock ownership in Spinicity/ISD; has received clinical/research support for this study from NREF; has received royalties from DePuy Spine, Thieme Publishers, and Springer Publishers; received a grant from AOSpine.

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Supplemental Digital Content. Table. Sensitivity analysis using complete case analysis.