Minimally invasive versus open lumbar spinal fusion: a matched study investigating patient-reported and surgical outcomes

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OBJECTIVE With the expanding indications for and increasing popularity of minimally invasive surgery (MIS) for lumbar spinal fusion, large-scale outcomes analysis to compare MIS approaches with open procedures is warranted.

METHODS The authors queried the Quality Outcomes Database for patients who underwent elective lumbar fusion for degenerative spine disease. They performed optimal matching, at a 1:2 ratio between patients who underwent MIS and those who underwent open lumbar fusion, to create two highly homogeneous groups in terms of 33 baseline variables (including demographic characteristics, comorbidities, symptoms, patient-reported scores, indications, and operative details). The outcomes of interest were overall satisfaction, decrease in Oswestry Disability Index (ODI), and back and leg pain, as well as hospital length of stay (LOS), operative time, reoperations, and incidental durotomy rate. Satisfaction was defined as a score of 1 or 2 on the North American Spine Society scale. Minimal clinically important difference (MCID) in ODI was defined as ≥ 30% decrease from baseline. Outcomes were assessed at the 3- and 12-month follow-up evaluations.

RESULTS After the groups were matched, the MIS and open groups consisted of 1483 and 2966 patients, respectively. Patients who underwent MIS fusion had higher odds of satisfaction at 3 months (OR 1.4, p = 0.004); no difference was demonstrated at 12 months (OR 1.04, p = 0.67). Lumbar stenosis, single-level fusion, higher American Society of Anesthesiologists Physical Status Classification System grade, and absence of spondylolisthesis were most prominently associated with higher odds of satisfaction with MIS compared with open surgery. Patients in the MIS group had slightly lower ODI scores at 3 months (mean difference 1.61, p = 0.006; MCID OR 1.14, p = 0.0495) and 12 months (mean difference 2.35, p < 0.001; MCID OR 1.29, p < 0.001). MIS was also associated with a greater decrease in leg and back pain at both follow-up time points. The two groups did not differ in operative time and incidental durotomy rate; however, LOS was shorter for the MIS group. Revision surgery at 12 months was less likely for patients who underwent MIS (4.1% vs 5.6%, p = 0.032).

CONCLUSIONS In patients who underwent lumbar fusion for degenerative spinal disease, MIS was associated with higher odds of satisfaction at 3 months postoperatively. No difference was demonstrated at the 12-month follow-up. MIS maintained a small, yet consistent, superiority in decreasing ODI and back and leg pain, and MIS was associated with a lower reoperation rate.

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KEYWORDS lumbar spinal fusion; minimally invasive surgery; Quality Outcomes Database; QOD; patient-reported outcomes; degenerative; tubular retractor; optimal matching

ABBREVIATIONS ASA = American Society of Anesthesiologists Physical Status Classification System; LOS = length of stay; MCID = minimal clinically important difference; MIS = minimally invasive surgery; NASS = North American Spine Society; NNT = number needed to treat; ODI = Oswestry Disability Index; PRO = patient-reported outcome; QOD = Quality Outcomes Database; SMD = standardized mean difference; VAS = visual analog scale.

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Lumbar spinal fusion is commonly used to stabilize patients with degenerative disease, spondylolisthesis, lumbar stenosis, and other spine conditions. These surgical procedures have traditionally been performed using open techniques; however, open spine surgery involves increased trauma to the muscle and soft tissues of the spine, leading to prolonged recovery times. Minimally invasive surgery (MIS) techniques allow removal of tissue from the surgeon's visual field without the need to make a large exposing incision, thereby sparing surrounding tissue.

MIS for lumbar spinal fusion reduces trauma to adjacent tissue and is associated with a reduced risk of muscle damage, less blood loss, and shorter hospital length of stay (LOS).[1–5] Although decreased blood loss and reduced postoperative pain have been associated with MIS, some studies have demonstrated no difference in clinical outcomes at 12 months, and others have demonstrated increased patient satisfaction with open decompression of low-grade spondylolisthesis.[3,4] Another study found no difference between the two approaches for 1-level fusion, with a greater decrease in leg pain in the MIS group.[6]

As MIS techniques become more popular, it is important to measure the success of these procedures by utilizing patient-reported outcomes (PROs). Large-scale studies that compare the outcomes of MIS approaches to those of traditional open procedures have not been performed. The primary objective of this study was to compare MIS and open surgery for lumbar spinal fusion by utilizing PROs from the lumbar spine surgery module of the Quality Outcomes Database (QOD).

Methods

The Quality Outcomes Database

The lumbar spine surgery module of the QOD registry was queried for this project. The QOD is a nationwide registry that was instituted in 2012 by the NeuroPoint Alliance. The QOD has impacted surgical outcomes research in the field of spine surgery mainly because of three unique features. First, the QOD is unique among databases in terms of scale and granularity. Second, the QOD includes PROs, such as pain on the visual analog scale (VAS), the Oswestry Disability Index (ODI), and patient satisfaction on the 4-point North American Spine Society (NASS) scale. These outcomes are of particular importance in spine surgery because they illustrate the primary aim of the intervention, namely to alleviate symptoms and improve quality of life.[7] Third, the QOD follows patients longitudinally, thereby providing insights into the long-term efficacy of surgical interventions.

Patient Cohort

The lumbar spine surgery module of the QOD contains data for more than 70,000 patients from 220 participating sites. For this project, only patients who underwent spinal fusion for degenerative indications with available 1-year follow-up data were included. Patients who underwent lumbar fusion via a posterior approach were included in the MIS group if surgery was performed with a tubular retractor. For anterior or lateral interbody fusions, surgery was considered MIS if screw fixation was performed percutaneously. The remaining patients were included in the open group.

Outcomes of Interest

The primary endpoints of this study were patient satisfaction and decrease from baseline in ODI at 3 months after surgery. Patient satisfaction was measured on the basis of the NASS scale; patients were considered satisfied if they had a NASS score of 1 or 2.

The secondary endpoints of this study included LOS, operative time, rate of incidental durotomy, readmission rate within 30 days, revision surgery rate at 3 and 12 months, and satisfaction and decrease in ODI at 12 months, as well as VAS scores for back pain and leg pain at 3 and 12 months. Minimal clinically important difference (MCID) in ODI and VAS scores was defined as a 30% decrease from baseline.[8] Optimal ODI at follow-up was defined as < 20, optimal VAS score for pain was defined as ≤ 2, and maximal satisfaction was defined as a NASS score equal to 1.

Statistical Analysis

Continuous data are presented as mean ± SD, and categorical data are presented as frequencies and proportions. The unpaired 2-sample t-test was performed for univariate analysis of continuous data, and Pearson's chi-square test was performed for categorical data. Multivariable logistic regression was performed to identify characteristics independently associated with the decision to perform either MIS or open lumbar fusion. The R language and RStudio environment (version 4.0.5) were used for all statistical analyses.[9] The results were considered statistically significant for $p < 0.05$. The rms package was utilized for logistic regression.

Optimal Matching

To create two highly homogeneous groups, we matched each patient in the MIS group with 2 patients in the open group via optimal matching. Optimal matching belongs to the family of matching techniques (which also includes propensity score and greedy matching) that are used to simulate randomization in observational studies. Optimal matching differs from propensity score matching in that patients are matched directly on the basis of their characteristics instead of the propensity score (the probability of receiving one treatment over the other) that these characteristics have.[10] Optimal matching is preferable to greedy matching because it pursues greater homogeneity of the total cohort instead of serially finding the ideal match (i.e., nearest neighbor) for individual patients.[11]

In randomized clinical trials, patients have the same probability of being allocated to each group. This feature guarantees that there is no selection bias and that the two arms differ only in terms of the treatment received; therefore, any difference in outcomes can be safely attributed to the effect of treatment. In observational studies, this hypothesis of equal probability of receiving each treatment can be approximated by utilizing matching techniques.[12] The rationale is that if the two groups contain patients who are highly similar in terms of the baseline characteristics that influence decision-making and postoperative outcomes, then one could safely assume that the differences in outcomes between the two groups are not products of confounders but instead due to differences in the treatment methods. Hence, the number and clinical significance of the variables used to match the two groups are critical for valid comparison.

In this study, we matched the MIS and open groups in terms of 33 baseline variables via optimal matching. The cutoff value of the standardized mean difference (SMD) for sufficient matching was set at less than 0.1.[13] A matching ratio of 1:2 was selected to increase the power of the study after making sure that the cutoff criteria for sufficient matching were not breached. The MatchIt package was utilized for the statistical analysis of optimal matching.

Results

Study Cohort

The lumbar module of the QOD included 72,504 patients. A total of 3363 patients underwent surgery for correction of deformity and were, therefore, beyond the scope of this study. Of the remaining 69,141 patients, 26,393 underwent procedures that included arthrodesis; the rest were excluded from further analysis. Furthermore, 543 of 2343 patients who underwent 2-stage surgery were excluded because one of the stages was MIS and the other was open surgery. Of 25,850 eligible patients, 19,921 patients (77%) were followed up for 3 months and 13,990 patients (54.1%) were followed up for 12 months. Finally, 11,213 patients (43.4%) with available data on all baseline and operative covariates of interest, as well as all PROs of interest at both time points, were included in the analysis.

The final patient group consisted of 11,213 patients included in the lumbar spine surgery module of the QOD. Of these patients, 9730 underwent open lumbar fusion and 1483 underwent MIS lumbar fusion for degenerative indications. The baseline characteristics of these groups are available in Table 1.

Predictors of MIS and Open Surgery

Multivariable logistic regression was performed to identify characteristics independently associated with the decision to perform either MIS or open lumbar fusion. Factors associated with the decision to perform open surgery were revision surgery, American Society of Anesthesiologists Physical Status Classification System (ASA) grades III and IV versus grades I and II, partially dependent ambulatory status, high school education or less, adjacent-segment disease, mechanical disc collapse, pseudarthrosis, ≥ 2 levels treated, 2-stage surgery, weakness/numbness/tingling as the predominant symptoms versus pain, and anxiety. Private insurance status was independently associated with MIS compared with open fusion (Fig. 1).

Optimal Matching and Key PROs

Patients who underwent MIS for lumbar spinal fusion (n = 1483) were matched in a 1:2 fashion with those who underwent open lumbar spinal fusion (n = 2966) in terms of 33 variables; the baseline characteristics of the matched patients are shown in Table 2. After matching, the mean ± SD age was 61.6 ± 12.0 years, BMI was 30.8 ± 6.3 kg/m^2, and 54.3% of patients were female. All SMDs were less than 0.1, indicating sufficient matching between the two groups.

Overall, a greater proportion of patients who underwent MIS for lumbar fusion had high satisfaction (NASS score 1–2) at 3 months postoperatively than those who underwent open lumbar fusion (92.9% vs 90.3%, p = 0.004; number needed to treat [NNT] 39). A greater proportion of patients in the MIS group also had maximal satisfaction (NASS score 1) at 3 months than the open lumbar fusion group (74.0% vs 69.8%, p = 0.003; NNT 24). The mean ± SD decrease from baseline ODI at 3 months was significantly greater in the MIS group (21.1 ± 18.4 vs 19.5 ± 18.3, p = 0.006) (Fig. 2). At 12 months postoperatively, overall satisfaction was comparable between MIS and open lumbar fusion patients (86.6% vs 86.1% of patients, p = 0.666); however, decrease from baseline ODI remained significantly greater in the MIS group (24.6 ± 19.2 vs 22.3 ± 19.3, p < 0.0001) (Fig. 2).

Overall Satisfaction at 3 Months

Demographic Characteristics

When examining age (< 58, 58–67, and ≥ 68 years), we determined that patients < 58 years had higher odds of achieving satisfaction with MIS than patients who underwent open lumbar fusion (OR 1.82, 95% CI 1.23–2.68, p = 0.003), although all age groups trended toward higher satisfaction with MIS (Fig. 3). Patients with BMI ≥ 30 had high odds of achieving satisfaction with MIS lumbar fusion (OR 1.38, 95% CI 1.01–1.91, p = 0.044). This was also true for those with BMI < 30, although this finding was not significant (OR 1.4, 95% CI 1.00–1.97, p = 0.053). Male sex (OR 1.65, 95% CI 1.17–2.33, p = 0.005) and White race (OR 1.45, 95% CI 1.11–1.88, p = 0.006) were also associated with higher odds of satisfaction after MIS lumbar fusion.

Anatomical and Surgical Factors

The absence of grade I spondylolisthesis (OR 1.54, 95% CI 1.09–2.18, p = 0.014) and the presence of lumbar stenosis (OR 1.59, 95% CI 1.17–2.17, p = 0.003) were associated with higher odds of satisfaction after MIS lumbar fusion. Single-level MIS fusion was also associated with higher overall odds of satisfaction (OR 1.54, 95% CI 1.18–2.02, p = 0.002) than multilevel MIS fusion. Primary surgery was associated with higher odds of overall satisfaction with MIS fusion (OR 1.44, 95% CI 1.12–1.86, p = 0.005) than revision surgery (OR 1.27, 95% CI 0.72–2.22, p = 0.408).

Twelve-Month Follow-Up and Other Endpoints

Oswestry Disability Index

Baseline ODI scores were similar between groups (45.1 for the MIS group vs 44.6 for the open surgery group, p = 0.407); however, patients who underwent MIS lumbar fusion had lower ODI scores at 3 months (p = 0.036) and 12 months (p = 0.001) postoperatively than those who un-

TABLE 1. Baseline characteristics of the patients who underwent MIS and open lumbar fusion prior to matching

Characteristic	Open (n = 9730)	MIS (n = 1483)	Total (n = 11,213)	p Value	SMD
Age, yrs	62.419 (11.678)	61.652 (11.627)	62.318 (11.674)	**0.018**	0.066
BMI, kg/m^2	30.933 (6.222)	30.541 (6.225)	30.881 (6.224)	**0.024**	0.063
Smoker	1245 (12.8)	162 (10.9)	1407 (12.5)	**0.043**	0.058
Female sex	5316 (54.6)	801 (54.0)	6117 (54.6)	0.654	0.013
Revision	1765 (18.1)	180 (12.1)	1945 (17.3)	**<0.001**	**0.168**
Osteoporosis	626 (6.4)	84 (5.7)	710 (6.3)	0.257	0.032
Diabetes mellitus	2045 (21.0)	256 (17.3)	2301 (20.5)	**<0.001**	0.096
ASA grade				**<0.001**	**0.183**
I	188 (1.9)	52 (3.5)	240 (2.1)		
II	4618 (47.5)	798 (53.8)	5416 (48.3)		
III	4791 (49.2)	625 (42.1)	5416 (48.3)		
IV	133 (1.4)	8 (0.5)	141 (1.3)		
Ambulation				**<0.001**	0.154
Independent	8162 (84.0)	1327 (89.5)	9489 (84.7)		
Partially dependent	1492 (15.3)	147 (9.9)	1639 (14.6)		
Totally dependent	67 (0.7)	9 (0.6)	76 (0.7)		
Education level				**<0.001**	**0.100**
Not available	257 (2.6)	24 (1.6)	281 (2.5)		
High school or less	4744 (48.8)	652 (44.0)	5396 (48.1)		
Graduate level	3473 (35.7)	608 (41.0)	4081 (36.4)		
Postgraduate level	1256 (12.9)	199 (13.4)	1455 (13.0)		
Symptomatic disc herniation	1702 (17.5)	287 (19.4)	1989 (17.7)	0.081	0.048
Grade I spondylolisthesis	5270 (54.2)	875 (59.0)	6145 (54.8)	**<0.001**	0.098
Lumbar stenosis	5540 (56.9)	813 (54.8)	6353 (56.7)	0.126	0.043
Adjacent-segment disease	1148 (11.8)	89 (6.0)	1237 (11.0)	**<0.001**	**0.205**
Single-level symptomatic mechanical disc collapse	222 (2.3)	12 (0.8)	234 (2.1)	**<0.001**	**0.120**
Pseudarthrosis	219 (2.3)	6 (0.4)	225 (2.0)	**<0.001**	**0.162**
ODI at baseline	46.570 (15.904)	45.061 (15.771)	46.371 (15.894)	**<0.001**	0.095
VAS					
Leg pain	6.613 (2.781)	6.567 (2.784)	6.607 (2.781)	0.554	0.016
Back pain	6.971 (2.450)	6.764 (2.604)	6.944 (2.471)	**0.003**	0.082
Race					
African American	604 (6.2)	112 (7.6)	716 (6.4)	**0.049**	0.053
White	8711 (89.5)	1317 (88.8)	10,028 (89.4)	0.400	0.023
Other	230 (2.4)	34 (2.3)	264 (2.4)	0.866	0.005
Insurance				**<0.001**	**0.206**
Medicare	4624 (47.5)	617 (41.6)	5241 (46.7)		
Medicaid	409 (4.2)	33 (2.2)	442 (3.9)		
Private	4306 (44.3)	791 (53.3)	5097 (45.5)		
Uninsured	61 (0.6)	4 (0.3)	65 (0.6)		
Veterans Affairs/government	330 (3.4)	38 (2.6)	368 (3.3)		
Workers' compensation	272 (2.8)	23 (1.6)	295 (2.6)	**0.005**	0.085
Liability claim	437 (4.5)	43 (2.9)	480 (4.3)	**0.005**	0.084
No. of levels fused	1.441 (0.639)	1.220 (0.471)	1.412 (0.624)	**<0.001**	**0.394**
Levels fused				**<0.001**	**0.394**
1	6224 (64.0)	1194 (80.5)	7418 (66.2)		
2	2721 (28.0)	252 (17.0)	2973 (26.5)		
3	785 (8.1)	37 (2.5)	822 (7.3)		
Interbody graft	8834 (90.8)	1359 (91.6)	10,193 (90.9)	0.291	0.030

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TABLE 1. Baseline characteristics of the patients who underwent MIS and open lumbar fusion prior to matching

Characteristic	Open (n = 9730)	MIS (n = 1483)	Total (n = 11,213)	p Value	SMD
Surgical approach				**<0.001**	0.039
Posterior	8569 (88.1)	1299 (87.6)	9868 (88.0)		
Anterior	378 (3.9)	18 (1.2)	396 (3.5)		
Lateral	135 (1.4)	105 (7.1)	240 (2.1)		
2-stage	648 (6.7)	61 (4.1)	709 (6.3)		
Predominant symptom				**<0.001**	**0.193**
Pain	8593 (88.3)	1392 (93.9)	9985 (89.0)		
Weakness	320 (3.3)	28 (1.9)	348 (3.1)		
Numbness/tingling	817 (8.4)	63 (4.2)	880 (7.8)		
Predominant location of pain				0.393	0.035
Back	2796 (28.8)	401 (27.0)	3197 (28.5)		
Leg	2262 (23.3)	351 (23.7)	2613 (23.3)		
Back & leg	4667 (48.0)	731 (49.3)	5398 (48.2)		
Symptom duration, mos				**0.011**	0.076
<3	428 (4.4)	50 (3.4)	478 (4.3)		
>3	9216 (94.7)	1410 (95.1)	10,626 (94.8)		
Unknown	86 (0.9)	23 (1.6)	109 (1.0)		
Depression	2430 (25.0)	306 (20.6)	2736 (24.4)	**<0.001**	**0.104**
Anxiety	1911 (19.6)	199 (13.4)	2110 (18.8)	**<0.001**	**0.168**

Values are shown as number (percent) or mean (SD) unless indicated otherwise. Boldface type indicates statistical significance ($p < 0.05$).

derwent open lumbar fusion (Table 3). The decreases from baseline ODI at 3 months (21.1 ± 18.4 vs 19.5 ± 18.3, p = 0.006) and 12 months (24.6 ± 19.2 vs 22.3 ± 19.3; p < 0.0001) were also greater in the MIS group (Fig. 2). The proportion of patients who achieved optimal ODI (< 20) was also significantly greater in the MIS group than the open group at 3 months (47.6% vs 43.8%, p = 0.016; NNT 26) and 12 months (55.2% vs 51.6%, p = 0.026; NNT 32).

Leg and Back Pain

Patients who underwent MIS fusion had a greater postoperative decrease than the open fusion group in both back and leg pain at 3 months (decrease in back pain VAS 3.89 vs 3.55, p < 0.001; decrease in leg pain VAS 4.49 vs 4.19, p = 0.008) and 12 months (decrease in back pain 3.96 vs 3.60, p < 0.001; decrease in leg pain 4.45 vs 4.10, p = 0.002) (Fig. 2). A greater proportion of MIS patients also achieved minimal back pain (≤ 2 on VAS) at both 3 months (51.2% vs 46.7%, p = 0.005) and 12 months (53.7% vs 49.7%, p = 0.013) and minimal leg pain at 12 months (66.8% vs 62.5%, p = 0.006) (Table 4).

Minimal Clinically Important Difference

An MCID of 30% in ODI was achieved in a greater proportion of MIS patients than open fusion patients at 3 months (68.2% vs 65.2% of patients, p = 0.049) and 12 months (74.6% vs 69.4%, p < 0.001). MCID for back and leg pain was also achieved by a higher proportion of MIS patients than open fusion patients at both 3 months (76.4% vs 72.7% for back pain, p = 0.008; 81.0% vs 77.5% for leg pain, p = 0.007) and 12 months (74.7% vs 71.1% for back pain, p = 0.011; 80.1% vs 75.3% for leg pain, p < 0.001) (Tables 3 and 4).

Other Clinical Outcomes

LOS was significantly shorter for the MIS lumbar fusion group than for the open fusion group (2.46 vs 2.84 days, p < 0.001). Revision surgery within 12 months of initial surgery was performed on a greater proportion of patients in the open surgery group (5.6% vs 4.1%, p = 0.032; NNT 66); however, the proportions of patients who underwent revision surgery within 3 months were similar between groups (2.6% vs 2.8%, p = 0.704) (Table 3). Length of surgery, incidental durotomy rates, and readmission within 30 days were not significantly different between groups.

Subgroup Analysis

Clinical outcomes were examined in subgroups determined on the basis of indication for surgery. Key PROs for the various surgical indications are displayed in Table 5.

Lumbar Stenosis

Patients with lumbar stenosis achieved greater satisfaction at 3 months after MIS than patients who underwent open surgery (p = 0.003) and also demonstrated a greater decrease in ODI at 12 months (p = 0.003). Decreases in leg and back pain (both overall and MCID) were also significantly greater in patients who underwent MIS compared with those who underwent open surgery.

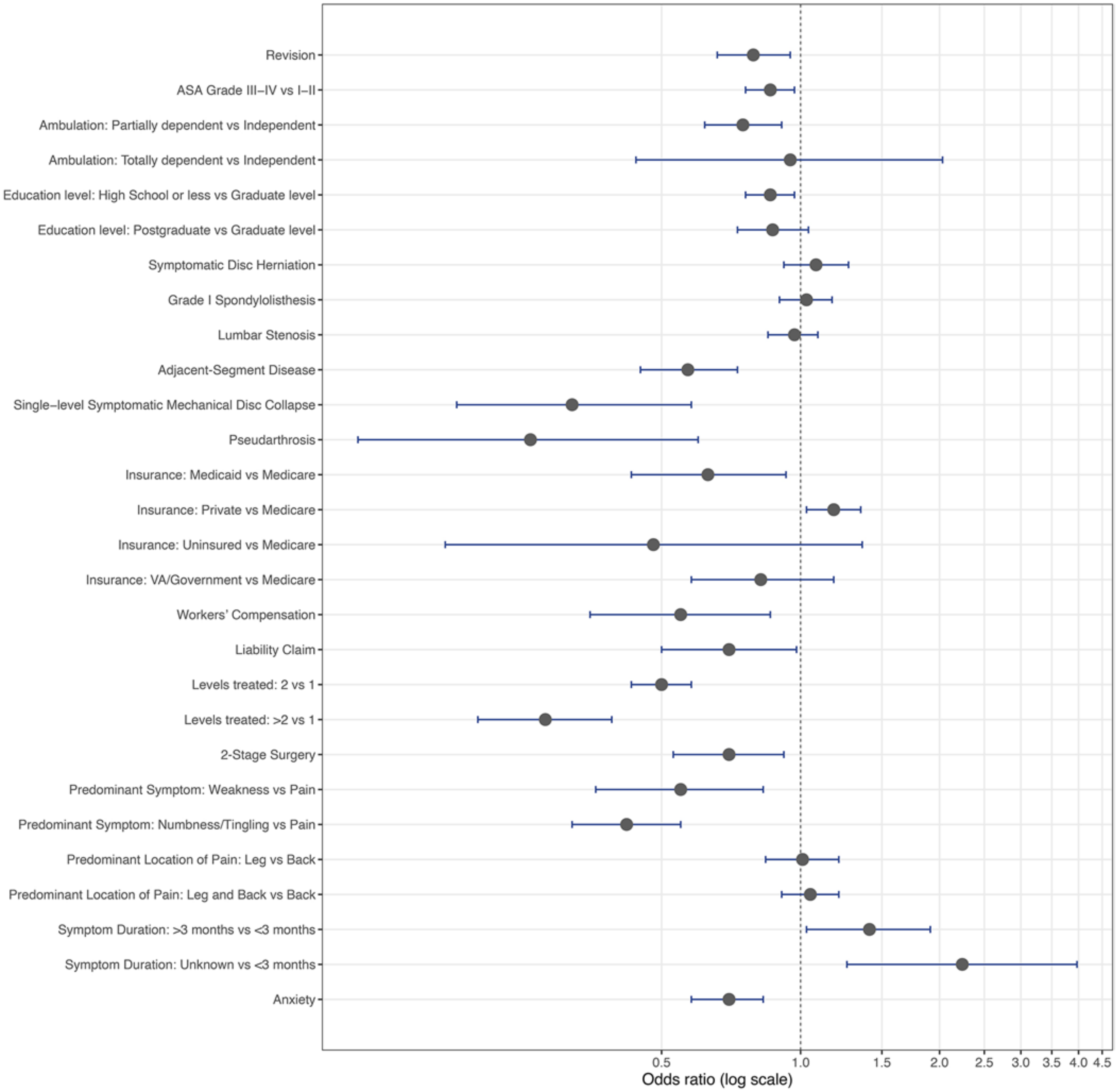

FIG. 1. Multivariable analysis of characteristics independently associated with patients who underwent MIS. VA = Veterans Affairs. Figure is available in color online only.

Grade I Spondylolisthesis

Patients with grade I spondylolisthesis demonstrated a greater decrease from baseline ODI at 12 months after MIS, but these patients did not demonstrate significant differences in satisfaction at 3 or 12 months or change in ODI at 3 months. Decreases in leg and back pain at 3 and 12 months were greater with MIS compared with open fusion.

Disc Herniation

There were no significant differences in the key endpoints between MIS and open fusion; however, patients who underwent MIS had significantly greater improvements in leg pain (both decrease and overall MCID at 3 and 12 months) and back pain at 3 months.

Adjacent-Segment Disease

Satisfaction was significantly higher at 3 and 12 months, and decrease in ODI was greater at 3 months, in patients who underwent MIS. Additionally, MCID for leg pain was greater at 3 months in patients who underwent MIS.

TABLE 2. Baseline characteristics of the patients who underwent MIS and open lumbar fusion after matching

Characteristic	Open (n = 2966)	MIS (n = 1483)	Total (n = 4449)	p Value	SMD
Age, yrs	61.557 (12.182)	61.652 (11.627)	61.588 (11.999)	0.803	0.008
BMI, kg/m^2	31.001 (6.323)	30.541 (6.225)	30.848 (6.294)	**0.022**	0.073
Smoker	324 (10.9)	162 (10.9)	486 (10.9)	>0.99	<0.001
Female sex	1614 (54.4)	801 (54.0)	2415 (54.3)	0.798	0.008
Revision	329 (11.1)	180 (12.1)	509 (11.4)	0.302	0.033
Osteoporosis	190 (6.4)	84 (5.7)	274 (6.2)	0.332	0.031
Diabetes mellitus	530 (17.9)	256 (17.3)	786 (17.7)	0.617	0.016
ASA grade				0.449	0.019
I	94 (3.2)	52 (3.5)	146 (3.3)		
II	1654 (55.8)	798 (53.8)	2452 (55.1)		
III	1195 (40.3)	625 (42.1)	1820 (40.9)		
IV	23 (0.8)	8 (0.5)	31 (0.7)		
Ambulation				0.137	0.054
Independent	2597 (87.6)	1327 (89.5)	3924 (88.2)		
Partially dependent	353 (11.9)	147 (9.9)	500 (11.2)		
Totally dependent	16 (0.5)	9 (0.6)	25 (0.6)		
Education level				0.059	0.031
High school or less	1380 (46.5)	652 (44.0)	2032 (45.7)		
Graduate level	1095 (36.9)	608 (41.0)	1703 (38.3)		
Postgraduate level	431 (14.5)	199 (13.4)	630 (14.2)		
Not available	60 (2.0)	24 (1.6)	84 (1.9)		
Symptomatic disc herniation	618 (20.8)	287 (19.4)	905 (20.3)	0.247	0.037
Grade I spondylolisthesis	1750 (59.0)	875 (59.0)	2625 (59.0)	>0.99	<0.001
Lumbar stenosis	1563 (52.7)	813 (54.8)	2376 (53.4)	0.181	0.043
Adjacent-segment disease	157 (5.3)	89 (6.0)	246 (5.5)	0.330	0.031
Single-level symptomatic mechanical disc collapse	19 (0.6)	12 (0.8)	31 (0.7)	0.524	0.020
Pseudarthrosis	8 (0.3)	6 (0.4)	14 (0.3)	0.449	0.023
ODI at baseline	44.651 (15.390)	45.061 (15.771)	44.788 (15.517)	0.407	0.026
VAS					
Leg pain	6.505 (2.804)	6.567 (2.784)	6.526 (2.797)	0.486	0.022
Back pain	6.698 (2.572)	6.764 (2.604)	6.720 (2.582)	0.419	0.026
Race					
African American	229 (7.7)	112 (7.6)	341 (7.7)	0.842	0.006
White	2620 (88.3)	1317 (88.8)	3937 (88.5)	0.642	0.015
Other	98 (3.3)	34 (2.3)	132 (3.0)	0.061	0.061
Insurance				**0.001**	0.023
Medicare	1229 (41.4)	617 (41.6)	1846 (41.5)		
Medicaid	108 (3.6)	33 (2.2)	141 (3.2)		
Private	1485 (50.1)	791 (53.3)	2276 (51.2)		
Uninsured	20 (0.7)	4 (0.3)	24 (0.5)		
Veterans Affairs/government	124 (4.2)	38 (2.6)	162 (3.6)		
Workers' compensation	56 (1.9)	23 (1.6)	79 (1.8)	0.422	0.026
Liability claim	76 (2.6)	43 (2.9)	119 (2.7)	0.511	0.021
No. of levels fused	1.233 (0.493)	1.220 (0.471)	1.229 (0.486)	0.383	0.028
Levels fused				0.422	0.028
1	2369 (79.9)	1194 (80.5)	3563 (80.1)		
2	502 (16.9)	252 (17.0)	754 (16.9)		
3	95 (3.2)	37 (2.5)	132 (3.0)		
Interbody graft	2684 (90.5)	1359 (91.6)	4043 (90.9)	0.211	0.040

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TABLE 2. Baseline characteristics of the patients who underwent MIS and open lumbar fusion after matching

Characteristic	Open (n = 2966)	MIS (n = 1483)	Total (n = 4449)	p Value	SMD
Surgical approach				**<0.001**	0.064
Posterior	2583 (87.1)	1299 (87.6)	3882 (87.3)		
Anterior	165 (5.6)	18 (1.2)	183 (4.1)		
Lateral	93 (3.1)	105 (7.1)	198 (4.5)		
2-stage surgery	125 (4.2)	61 (4.1)	186 (4.2)		
Predominant symptom				0.334	0.021
Pain	2760 (93.1)	1392 (93.9)	4152 (93.3)		
Weakness	77 (2.6)	28 (1.9)	105 (2.4)		
Numbness/tingling	129 (4.3)	63 (4.2)	192 (4.3)		
Predominant location of pain				0.870	0.017
Back	783 (26.4)	401 (27.0)	1184 (26.6)		
Leg	698 (23.5)	351 (23.7)	1049 (23.6)		
Back & leg	1485 (50.1)	731 (49.3)	2216 (49.8)		
Symptom duration, mos				0.814	0.014
<3	102 (3.4)	50 (3.4)	152 (3.4)		
>3	2825 (95.2)	1410 (95.1)	4235 (95.2)		
Unknown	39 (1.3)	23 (1.6)	62 (1.4)		
Depression	631 (21.3)	306 (20.6)	937 (21.1)	0.621	0.016
Anxiety	348 (11.7)	199 (13.4)	547 (12.3)	0.106	0.051

Values are shown as number (percent) or mean (SD) unless indicated otherwise. Boldface type indicates statistical significance ($p < 0.05$).

Discussion

The indications for the treatment of degenerative lumbar pathology with MIS technologies continue to expand as these procedures become more and more popular. MIS approaches involve tissue-sparing techniques with smaller incisions and have been associated with diminished blood loss, operative times, and hospital LOS.[14–18] Prior studies have also shown that MIS approaches have equivalent surgical complications to open procedures, but with a lower rate of medical complications.[19]

To date, this is the largest multicenter database study to examine patient outcomes after MIS versus those after open lumbar spinal fusion by utilizing the lumbar spine surgery module of the QOD. After logistic regression analysis and optimal 1:2 matching for 33 baseline variables, ORs for overall satisfaction with MIS lumbar fusion versus those for open lumbar fusion were calculated across several patient characteristics in an effort to determine the patient populations most likely to benefit from MIS for lumbar fusion. Overall, MIS for lumbar fusion was found to be superior to open lumbar fusion in terms of satisfaction at 3 months postoperatively, but no such difference was observed at 12 months.

Several prior single-institution and multicenter studies have been performed to compare MIS and open treatment of degenerative lumbar disease; however, the majority have demonstrated similar improvements regardless of approach.[16–18] Mummaneni et al. previously utilized the QOD to examine MIS versus open single-level fusion for grade I degenerative lumbar spondylolisthesis, but no significant differences between groups were found; significant improvement in all functional outcomes was noted in both groups.[6] Similarly, McGirt et al. examined patients who underwent either MIS or open 1- to 2-level interbody fusion for lumbar stenosis or spondylolisthesis, and they found reduced blood loss and LOS in patients who underwent MIS without associated improvements in 12-month outcomes.[4] Examining patients identified in the QOD who underwent only MIS versus open decompression for low-grade spondylolisthesis, Bisson et al. found comparable PROs and clinical outcomes at 2 years.[3]

Although these prior similar studies have also utilized the QOD, some features differentiate the index study. More specifically, in this study, we utilized a significantly larger and demographically heterogeneous volume of patients, which adds significant power to the comparative analysis and enhances the generalizability of the results. Additionally, contrary to previous studies that used multivariable analysis to adjust for confounders, in this study we performed optimal matching to adjust for confounders. This method allowed us to adjust for confounders directly, potentially providing significant mitigation of selection bias.[10]

This is one of the first studies to demonstrate a statistically significant higher odds of short-term (3-month) satisfaction with MIS lumbar fusion compared with open lumbar fusion, with similar overall satisfaction at 12 months. In addition, MIS lumbar fusion was associated with greater decreases in the ODI and back and leg pain, a greater percentage of patients who achieved optimal ODI and optimal back pain, and a greater percentage of patients who achieved MCID of 30% for back pain, leg pain, and ODI at both 3 and 12 months postoperatively. Despite the ro-

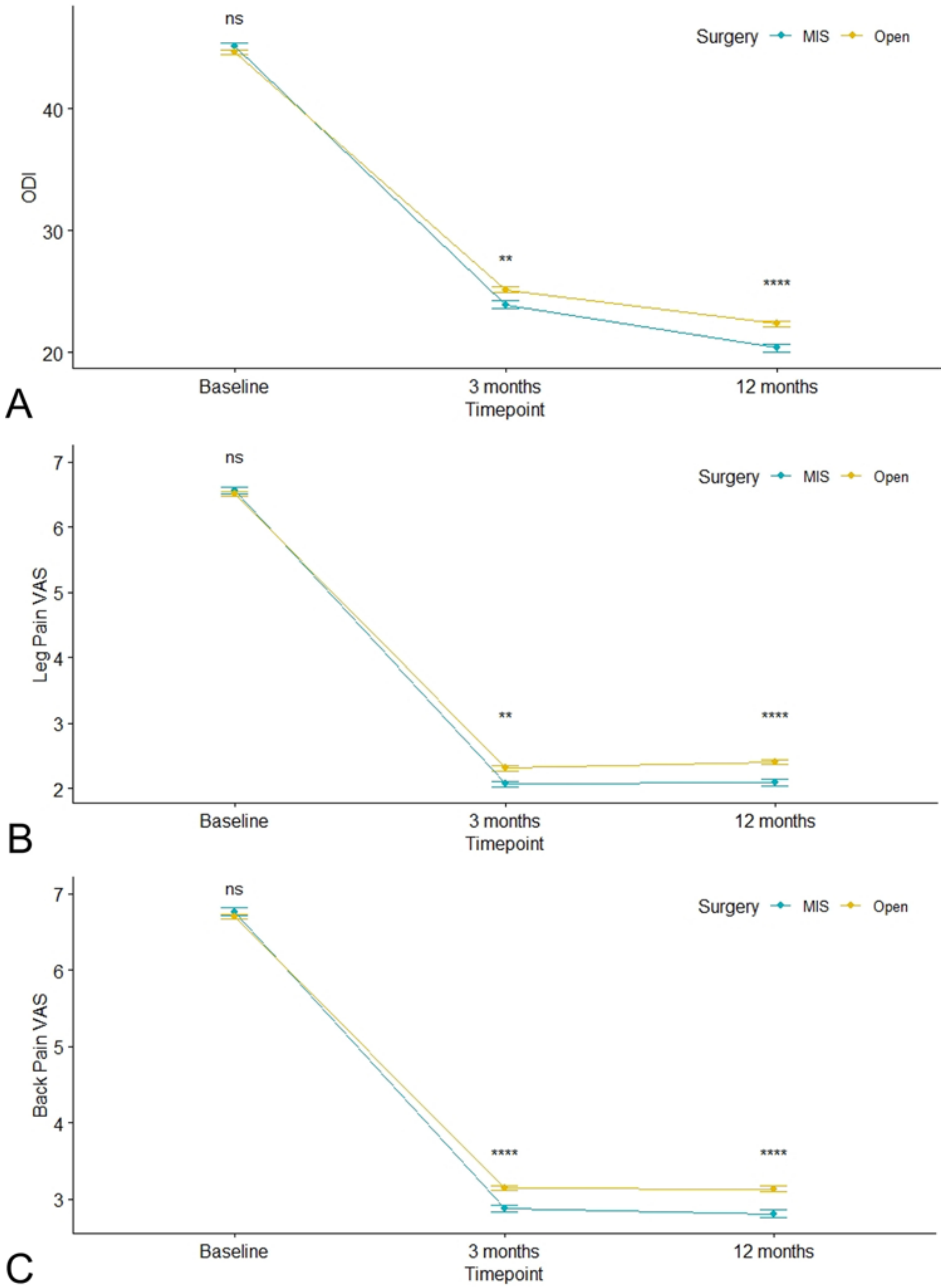

FIG. 2. Timelines of changes in PROs of the MIS and open groups. Changes in ODI (**A**), leg pain VAS (**B**), and back pain VAS (**C**) are shown. ns = not significant. **p < 0.01; ****p < 0.0001. Figure is available in color online only.

bust statistical significance of these findings, their clinical impact is limited because of the small absolute values of these differences, potentially disputing the clinical significance of these findings. However, given the high similarity between the two groups, differences in outcomes should be predominantly attributed to the surgical technique, and such differences are not expected to be vast.

There is a learning curve for the optimal implementation of all emerging technologies, and it may be that MIS technology is reaching its "plateau of productivity" with the increasing realization of its benefits.[20] Assessment of a learning curve was not feasible in the index study because the majority of the MIS operations took place in a relatively short period (2015–2018). Recent improvements in MIS technology, in combination with its more widespread use and increasing familiarity among surgeons, may explain the present novel findings.

This study also demonstrated a specific benefit of MIS fusion for several patient subgroups, including those with age ≤ 55 years, men, White patients, those undergoing first-time surgery or single-level surgery, those with lumbar stenosis, and those without spondylolisthesis. Addition-

Subgroup	No. of Patients MIS	No. of Patients Open	Satisfaction, n (%) MIS	Satisfaction, n (%) Open	Unadjusted Odds Ratio (95% CI) Odds of Achieving Satisfaction with MIS (>1) vs Open (<1)	p Value
Overall	1483	2966	1377 (92.9%)	2677 (90.3%)	1.4 (1.11 - 1.77)	**0.004**
Age						
<58	484	950	448 (92.6%)	829 (87.3%)	1.82 (1.23 - 2.68)	**0.003**
58-67	492	970	463 (94.1%)	895 (92.3%)	1.34 (0.86 - 2.08)	**0.198**
≥68	507	1046	466 (91.9%)	953 (91.1%)	1.11 (0.76 - 1.63)	**0.597**
BMI						
<30	771	1439	722 (93.6%)	1314 (91.3%)	1.4 (1 - 1.97)	0.053
≥30	712	1527	655 (92.0%)	1363 (89.3%)	1.38 (1.01 - 1.91)	**0.044**
Gender						
Male	682	1352	636 (93.3%)	1208 (89.3%)	1.65 (1.17 - 2.33)	**0.005**
Female	801	1614	741 (92.5%)	1469 (91.0%)	1.22 (0.89 - 1.67)	0.216
White Race						
Yes	1317	2620	1236 (93.8%)	2393 (91.3%)	1.45 (1.11 - 1.88)	**0.006**
No	166	346	141 (84.9%)	284 (82.1%)	1.23 (0.74 - 2.04)	0.421
Afr. American Race						
Yes	112	229	93 (83.0%)	185 (80.8%)	1.16 (0.64 - 2.11)	0.615
No	1371	2737	1284 (93.7%)	2492 (91.0%)	1.45 (1.13 - 1.87)	**0.004**
Osteoporosis						
Yes	84	190	82 (97.6%)	167 (87.9%)	5.65 (1.3 - 24.53)	**0.021**
No	1399	2776	1295 (92.6%)	2510 (90.4%)	1.32 (1.04 - 1.67)	**0.022**
Anxiety						
Yes	199	348	185 (93.0%)	305 (87.6%)	1.86 (0.99 - 3.5)	0.053
No	1284	2618	1192 (92.8%)	2372 (90.6%)	1.34 (1.05 - 1.72)	**0.020**
Depression						
Yes	306	631	283 (92.5%)	562 (89.1%)	1.51 (0.92 - 2.47)	0.101
No	1177	2335	1094 (92.9%)	2115 (90.6%)	1.37 (1.05 - 1.78)	**0.019**
ASA Grade						
I or II	850	1748	794 (93.4%)	1598 (91.4%)	1.33 (0.97 - 1.83)	0.079
III or IV	633	1218	583 (92.1%)	1079 (88.6%)	1.5 (1.07 - 2.11)	**0.019**
Primary vs Revision						
Primary	1303	2637	1217 (93.4%)	2393 (90.7%)	1.44 (1.12 - 1.86)	**0.005**
Revision	180	329	160 (88.9%)	284 (86.3%)	1.27 (0.72 - 2.22)	0.408
Symptomatic DH						
Yes	287	618	262 (91.3%)	549 (88.8%)	1.32 (0.81 - 2.13)	0.261
No	1196	2348	1115 (93.2%)	2128 (90.6%)	1.42 (1.09 - 1.85)	**0.009**
Grade I Spond.						
Yes	875	1750	816 (93.3%)	1600 (91.4%)	1.3 (0.95 - 1.77)	0.104
No	608	1216	561 (92.3%)	1077 (88.6%)	1.54 (1.09 - 2.18)	**0.014**
Lumbar Stenosis						
Yes	813	1563	754 (92.7%)	1390 (88.9%)	1.59 (1.17 - 2.17)	**0.003**
No	670	1403	623 (93.0%)	1287 (91.7%)	1.19 (0.84 - 1.7)	0.322
ASD						
Yes	89	157	85 (95.5%)	134 (85.4%)	3.65 (1.22 - 10.9)	**0.021**
No	1394	2809	1292 (92.7%)	2543 (90.5%)	1.32 (1.04 - 1.68)	**0.020**
SSMDC						
Yes	12	19	10 (83.3%)	18 (94.7%)	0.28 (0.02 - 3.46)	0.320
No	1471	2947	1367 (92.9%)	2659 (90.2%)	1.42 (1.13 - 1.8)	**0.003**
Pseudarthrosis						
Yes	6	8	5 (83.3%)	7 (87.5%)	0.7 (0.04 - 14.35)	0.826
No	1477	2958	1372 (92.9%)	2670 (90.3%)	1.41 (1.12 - 1.78)	**0.004**
Pred. Symptom						
Pain	1392	2760	1293 (92.9%)	2491 (90.3%)	1.41 (1.11 - 1.79)	**0.005**
Weakness	28	77	25 (89.3%)	70 (90.9%)	0.83 (0.2 - 3.47)	0.802
Numbness/Tingling	63	129	59 (93.7%)	116 (89.9%)	1.65 (0.52 - 5.29)	0.397
Pred. Pain Location						
Back	401	783	375 (93.5%)	694 (88.6%)	1.85 (1.17 - 2.91)	**0.008**
Leg	351	698	335 (95.4%)	650 (93.1%)	1.55 (0.86 - 2.76)	0.141
Back and Leg	731	1485	667 (91.2%)	1333 (89.8%)	1.19 (0.87 - 1.61)	0.270
Symptom Duration						
< 3 Months	50	102	48 (96.0%)	96 (94.1%)	1.5 (0.29 - 7.71)	0.627
> 3 Months	1410	2825	1309 (92.8%)	2544 (90.1%)	1.43 (1.13 - 1.81)	**0.003**
Unknown	23	2825	20 (87.0%)	37 (94.9%)	0.36 (0.06 - 2.34)	0.285
# of Levels Fused						
1	1194	2369	1119 (93.7%)	2147 (90.6%)	1.54 (1.18 - 2.02)	**0.002**
2	252	502	226 (89.7%)	450 (89.6%)	1 (0.61 - 1.65)	0.986
3	37	95	32 (86.5%)	80 (84.2%)	1.2 (0.4 - 3.58)	0.743
Interbody Graft						
Yes	1359	2684	1261 (92.8%)	2425 (90.4%)	1.37 (1.08 - 1.75)	**0.010**
No	124	282	116 (93.5%)	252 (89.4%)	1.73 (0.77 - 3.88)	0.187

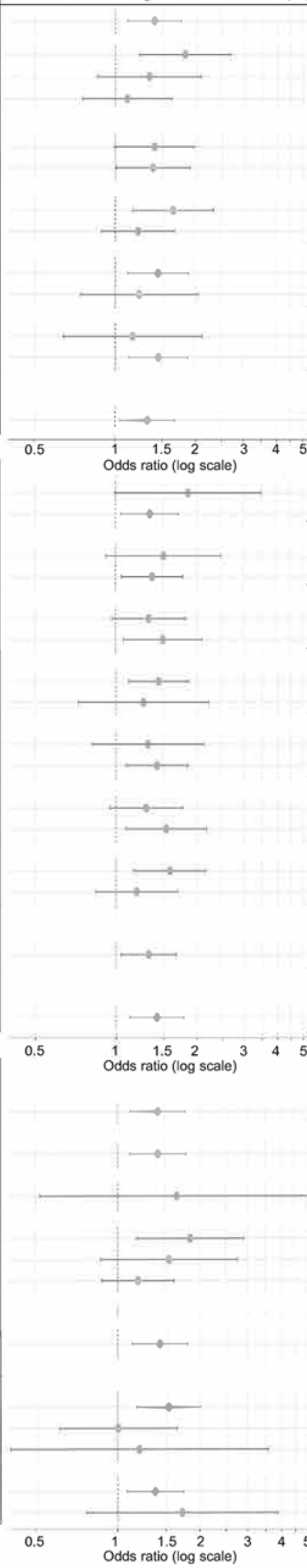

FIG. 3. Comparison of ORs of satisfaction with surgery (NASS score 1 or 2) between patients who underwent MIS and open approaches according to different patient characteristics. Afr. = African; ASD = adjacent-segment disease; DH = disc herniation; Pred. = predominant; Spond. = spondylolisthesis; SSMDC = single-level symptomatic mechanical disc collapse.

TABLE 3. Postoperative patient satisfaction, change in ODI, and clinical outcomes after MIS and open lumbar fusion

Characteristic	Open (n = 2966)	MIS (n = 1483)	Total (n = 4449)	p Value	NNT (95% CI)
Primary endpoints					
Satisfaction (NASS score 1–2) at 3 mos	2677 (90.3)	1377 (92.9)	4054 (91.1)	**0.004**	39 (23–110)
Max satisfaction (NASS score 1) at 3 mos	2069 (69.8)	1097 (74.0)	3166 (71.2)	**0.003**	24 (14–70)
ODI at baseline	44.651 (15.390)	45.061 (15.771)	44.788 (15.517)	0.407	
ODI at 3 mos	25.145 (18.155)	23.941 (17.792)	24.743 (18.042)	**0.036**	
Optimal ODI (<20) at 3 mos	1299 (43.8)	706 (47.6)	2005 (45.1)	**0.016**	26 (14–142)
Decrease from baseline ODI at 3 mos	19.506 (18.265)	21.120 (18.393)	20.044 (18.321)	**0.006**	
MCID (30%) in ODI at 3 mos	1934 (65.2)	1011 (68.2)	2945 (66.2)	**0.049**	33 (17–3287)
Secondary endpoints					
Satisfaction (NASS score 1–2) at 12 mos	2554 (86.1)	1284 (86.6)	3838 (86.3)	0.666	
Max satisfaction (NASS score 1) at 12 mos	1951 (65.8)	1004 (67.7)	2955 (66.4)	0.201	
ODI at 12 mos	22.364 (19.226)	20.377 (18.695)	21.702 (19.071)	**0.001**	
Optimal ODI (<20) at 12 mos	1520 (51.6)	812 (55.2)	2332 (52.8)	**0.026**	32 (17–259)
Decrease from baseline ODI at 12 mos	22.289 (19.338)	24.639 (19.176)	23.072 (19.314)	**<0.001**	
MCID (30%) in ODI at 12 mos	2043 (69.4)	1098 (74.6)	3141 (71.1)	**<0.001**	19 (13–41)
LOS, days	2.843 (1.663)	2.457 (2.809)	2.714 (2.122)	**<0.001**	
Length of surgery, mins	172.32 (72.946)	176.84 (83.355)	173.84 (76.613)	0.065	
Incidental durotomy	28 (1.4)	14 (1.3)	42 (1.4)	0.677	
Readmission w/in 30 days	98 (3.3)	48 (3.2)	146 (3.3)	0.911	
Revision surgery w/in 3 mos	76 (2.6)	41 (2.8)	117 (2.6)	0.704	
Revision surgery w/in 12 mos	154 (5.6)	60 (4.1)	214 (5.1)	**0.032**	66 (35–511)

Values are shown as number (percent) or mean (SD) unless indicated otherwise. Boldface type indicates statistical significance ($p < 0.05$).

ally, on the basis of 3-month satisfaction, subgroup analysis demonstrated that patients who underwent surgery for lumbar stenosis may be more likely to benefit from an MIS approach than those with spondylolisthesis or a disc herniation. However, it should be noted that all patients had significantly greater improvements in satisfaction and ODI with an MIS approach, regardless of surgical indication. It is likely that the numbers of patients in some subgroups

TABLE 4. Postoperative changes in leg and back pain (secondary endpoints) after MIS and open lumbar fusion

Characteristic	Open (n = 2966)	MIS (n = 1483)	Total (n = 4449)	p Value	NNT (95% CI)
VAS for leg pain at baseline	6.505 (2.804)	6.567 (2.784)	6.526 (2.797)	0.486	
VAS for leg pain at 3 mos	2.312 (2.829)	2.072 (2.608)	2.232 (2.760)	**0.006**	
Optimal leg pain (≤2 in VAS) at 3 mos	1885 (63.6)	982 (66.3)	2867 (64.5)	0.075	
Decrease in leg pain at 3 mos	4.192 (3.626)	4.494 (3.493)	4.293 (3.584)	**0.008**	
MCID (30%) in leg pain at 3 mos	2297 (77.5)	1200 (81.0)	3497 (78.7)	**0.007**	28 (17–97)
Leg pain at 12 mos	2.406 (2.924)	2.100 (2.741)	2.304 (2.868)	**<0.001**	
Optimal leg pain (≤2 in VAS) at 12 mos	1844 (62.5)	984 (66.8)	2828 (63.9)	**0.006**	24 (14–80)
Decrease in leg pain at 12 mos	4.103 (3.667)	4.453 (3.509)	4.220 (3.618)	**0.002**	
MCID (30%) in leg pain at 12 mos	2221 (75.3)	1181 (80.1)	3402 (76.9)	**<0.001**	21 (14–45)
VAS for back pain at baseline	6.698 (2.572)	6.764 (2.604)	6.720 (2.582)	0.419	
VAS for back pain at 3 mos	3.145 (2.600)	2.874 (2.447)	3.055 (2.553)	**<0.001**	
Optimal back pain (≤2 in VAS) at 3 mos	1386 (46.7)	758 (51.2)	2144 (48.2)	**0.005**	23 (13–76)
Decrease in back pain at 3 mos	3.553 (3.049)	3.889 (3.089)	3.665 (3.066)	**<0.001**	
MCID (30%) in back pain at 3 mos	2157 (72.7)	1132 (76.4)	3289 (74.0)	**0.008**	27 (17–100)
Back pain at 12 mos	3.134 (2.839)	2.805 (2.663)	3.024 (2.786)	**<0.001**	
Optimal back pain (≤2 in VAS) at 12 mos	1466 (49.7)	791 (53.7)	2257 (51.0)	**0.013**	25 (14–120)
Decrease in back pain at 12 mos	3.569 (3.188)	3.955 (3.197)	3.698 (3.196)	**<0.001**	
MCID (30%) in back pain at 12 mos	2096 (71.1)	1101 (74.7)	3197 (72.3)	**0.011**	28 (16–116)

Values are shown as number (percent) or mean (SD) unless indicated otherwise. Boldface type indicates statistical significance ($p < 0.05$).

TABLE 5. Subgroup analysis of key PROs according to indication for surgery

Indication	Open	MIS	p Value
Lumbar stenosis (n = 2376)	1563	813	
Satisfaction (NASS score 1–2) at 3 mos	1390 (88.9)	754 (92.7)	**0.003**
Satisfaction (NASS score 1–2) at 12 mos	1338 (85.6)	710 (87.3)	0.247
Decrease from baseline ODI at 3 mos	18.773 (17.939)	20.044 (18.230)	0.103
Decrease from baseline ODI at 12 mos	21.341 (19.324)	23.824 (18.727)	**0.003**
Decrease in leg pain at 12 mos	4.039 (3.616)	4.522 (3.502)	**0.002**
Decrease in back pain at 12 mos	3.516 (3.204)	4.037 (3.218)	**<0.001**
Grade I spondylolisthesis (n = 2625)	1750	875	
Satisfaction (NASS score 1–2) at 3 mos	1600 (91.4)	816 (93.3)	0.103
Satisfaction (NASS score 1–2) at 12 mos	1540 (88.0)	770 (88.0)	>0.99
Decrease from baseline ODI at 3 mos	19.800 (18.179)	20.912 (18.173)	0.140
Decrease from baseline ODI at 12 mos	22.599 (19.044)	25.124 (18.855)	**0.001**
Decrease in leg pain at 12 mos	4.294 (3.686)	4.525 (3.557)	0.128
Decrease in back pain at 12 mos	3.734 (3.266)	4.165 (3.200)	**0.001**
Disc herniation (n = 905)	618	287	
Satisfaction (NASS score 1–2) at 3 mos	549 (88.8)	262 (91.3)	0.260
Satisfaction (NASS score 1–2) at 12 mos	522 (84.5)	250 (87.1)	0.296
Decrease from baseline ODI at 3 mos	20.116 (18.663)	21.772 (19.115)	0.218
Decrease from baseline ODI at 12 mos	23.175 (20.015)	25.580 (19.650)	0.093
Decrease in leg pain at 12 mos	3.859 (3.643)	4.369 (3.345)	**0.046**
Decrease in back pain at 12 mos	3.293 (3.118)	3.692 (3.077)	0.074
Adjacent-segment disease (n = 246)	157	89	
Satisfaction (NASS score 1–2) at 3 mos	134 (85.4)	85 (95.5)	**0.014**
Satisfaction (NASS score 1–2) at 12 mos	119 (75.8)	78 (87.6)	**0.025**
Decrease from baseline ODI at 3 mos	16.937 (16.464)	21.930 (17.776)	**0.027**
Decrease from baseline ODI at 12 mos	17.614 (18.973)	20.985 (18.730)	0.183
Decrease in leg pain at 12 mos	4.090 (3.963)	3.977 (3.038)	0.818
Decrease in back pain at 12 mos	2.872 (3.311)	3.368 (2.910)	0.244

Values are shown as number, number (percent), or mean (SD) unless indicated otherwise. Boldface type indicates statistical significance ($p < 0.05$).

were not large enough to reveal significant differences between surgical approaches. Increased understanding of the preoperative factors that may influence optimal patient outcomes may aid physicians in counseling patients on the various surgical approaches for a specific pathology and choosing the optimal surgery for each patient.

Interestingly, private insurance status and education level were found to be independent predictors of the decision to perform MIS lumbar fusion on multivariate analysis, highlighting potential socioeconomic drivers for the use of MIS or open surgery.

Prior studies have shown that depression and anxiety impact short-term but not long-term PROs after lumbar surgery for spondylolisthesis.[21] Our study demonstrated improved 3-month satisfaction with MIS in both those with and those without anxiety and depression, although significance was not demonstrated likely because of inadequate sample size.

Interestingly, obesity (BMI ≥ 30) and higher ASA grades III and IV were significantly associated with improved satisfaction with MIS. Prior studies showed that higher BMI was associated with longer operative times, greater blood loss, and higher risks of surgical site infection and nerve injury, in addition to poorer PROs and satisfaction at 1 to 2 years of follow-up.[22–27] However, the tissue-sparing effects of MIS fusion may be more pronounced in obese patients, resulting in the greater improvement in satisfaction after MIS observed in this particular subgroup. Indeed, one prior systematic review demonstrated that although obese patients had greater surgical blood loss, longer operative times, and higher complication/reoperation rates, these differences were not significant in the subgroup of obese patients who underwent MIS.[23] Our study further corroborates these data.

Similar to most prior studies, the present study found that patients who underwent MIS fusion had an LOS that was approximately a half-day shorter than patients who underwent open surgery, with similar surgery times for both groups. Additionally, the durotomy rates, readmission rates, and rates of revision surgery within 3 months were not significantly different between groups, but the rate of revision surgery within 12 months was higher in the open group. Prior studies have demonstrated mixed results for durotomy rates between MIS and open approaches.[28–30]

Limitations

The limitations and weaknesses inherent to the current study have implications for its interpretation. First, this was an observational study, and patients were not randomly assigned to treatment groups. Although we employed optimal matching to reduce potential selection bias and the effects of confounders, it is possible that variables that were not collected and adjusted for could have affected the results. This is an inherent limitation of observational studies. Despite the final cohorts differing in terms of BMI and insurance status after optimal matching, SMD remained < 0.1 for all categories, thereby indicating optimal matching efficiency. Second, our length of follow-up was 1 year; as such, we can make no statements regarding the long-term comparative durability of MIS versus open technologies.

Additionally, inclusion of only patients with available 3- and 12-month follow-up could be another source of selection bias. Lastly, it is important to recognize that this is not an analysis of a specific MIS versus open approach, but rather an analysis of how surgeons in everyday care use MIS technologies in a variety of MIS approaches and how outcomes may be affected by those applications. The possibility that the surgeons who performed MIS were highly trained in this technique and, therefore, more likely to achieve optimal outcomes should be recognized. This scenario possibly limits the applicability of our conclusions to surgeons with less experience in MIS. Nevertheless, we included a diverse group of practices and patients to obtain a representative sample of patients who underwent elective lumbar spinal surgery, allowing these results to provide valuable evidence from a population health perspective.

Conclusions

In patients who underwent lumbar fusion for degenerative spine disease, MIS lumbar fusion was associated with higher odds of satisfaction and a greater decrease in ODI than open lumbar fusion at 3 months postoperatively. No statistically significant difference was demonstrated between patients who underwent MIS and those who underwent open lumbar fusion in terms of satisfaction at 12 months, but those who underwent MIS possibly maintained greater improvement in ODI. MIS was associated with a slightly greater decrease in back and leg pain, as well as lower 12-month reoperation rates. Additionally, overall durotomy and readmission rates are similar regardless of approach, with a shorter average LOS in patients who underwent MIS lumbar fusion. Independent factors associated with increased satisfaction with MIS lumbar fusion, compared with open surgery, included age < 58 years, first-time surgery, single-level surgery, lumbar stenosis, and absence of spondylolisthesis.

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Disclosures

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Conception and design: Mooney, Michalopoulos. Acquisition of data: Mooney. Analysis and interpretation of data: Michalopoulos. Drafting the article: Mooney, Michalopoulos, Zeitouni. Critically revising the article: Bydon, Chan, Mummaneni, Bisson, Haid, Pennicooke. Reviewed submitted version of manuscript: Bydon, Alvi, Chan, Mummaneni, Sherrod, Knightly, Devin, Asher. Statistical analysis: Michalopoulos, Alvi. Study supervision: Bydon, Bisson, Devin, Pennicooke, Asher.

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