

## Comparison of full-endoscopic and minimally invasive decompression for lumbar spinal stenosis in the setting of degenerative scoliosis and spondylolisthesis

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**OBJECTIVE** The management of lumbar spinal stenosis (LSS) with concurrent scoliosis and/or spondylolisthesis remains controversial. Full-endoscopic unilateral laminotomy for bilateral decompression (ULBD) facilitates neural decompression while preserving stabilizing osseoligamentous structures and may be uniquely suited for the treatment of LSS with concurrent mild to moderate degenerative deformity. The safety and efficacy of full-endoscopic versus minimally invasive surgery (MIS) ULBD in this patient population is studied here for the first time.

**METHODS** A retrospective analysis of prospectively collected data was conducted on 45 consecutive LSS patients with concurrent scoliosis ( $\geq 10^\circ$  coronal Cobb angle) and/or spondylolisthesis ( $\geq 3$  mm). Patient demographics, operative details, complications, and imaging characteristics were reviewed. Outcomes were quantified using back and leg visual analog scale (VAS) scores and the Oswestry Disability Index (ODI) at 2 weeks, 3 months, and 1 year.

**RESULTS** A total of 26 patients underwent full-endoscopic and 19 underwent MIS-ULBD with an average follow-up period of 12 months. The endoscopic cohort experienced a significantly shorter hospital length of stay ( $p = 0.014$ ) and fewer adverse events ( $p = 0.010$ ). Both cohorts experienced significant improvements in VAS and ODI scores at all time points ( $p < 0.001$ ), but the endoscopic cohort demonstrated significantly better early ODI scores ( $p = 0.024$ ).

**CONCLUSIONS** Endoscopic and MIS-ULBD result in similar functional outcomes for LSS with mild to moderate deformity, while the endoscopic approach demonstrates a favorable rate of complications. Further studies are required to better delineate the characteristics of spinal deformities amenable to this approach and the durability of functional results.

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**KEYWORDS** endoscopic spine surgery; stenosis; radiculopathy; minimally invasive spine surgery; MIS; scoliosis; unilateral laminotomy for bilateral decompression; ULBD

**L**UMBAR spinal stenosis (LSS) represents the most common indication for spine surgery in patients older than 65 years, with its prevalence expected to rise 59% to 64 million elderly adults by the year 2025.<sup>13,15,16,50</sup> While the treatment of patients with LSS without existing deformity or instability is primarily a decompressive procedure, there is a large subset of patients who have coexisting spondylolisthesis and/or degenerative deformity; the optimal treatment for these patients remains controversial.

The incidence and prevalence of degenerative scoliosis affecting adults has been reported variably, with curves greater than  $10^\circ$  present in more than 50% of elderly females with back pain and osteoporosis and a new onset of

deformity observed in over 30% of elderly patients.<sup>7,32,43</sup> A population-based study using the National (Nationwide) Inpatient Sample database found that 82.7% of patients with LSS with coexisting spondylolisthesis and 67.6% of patients with coexisting scoliosis underwent a fusion procedure, while only 26.2% of patients with LSS without instability underwent a fusion procedure.<sup>4</sup>

Treatment options depend largely on patient factors and clinical presentation; patients with severe back pain and disability from significant sagittal or coronal imbalance are unlikely to benefit from a minimalist decompressive approach given the underlying structural problem. Patients whose symptoms are predominantly radiculopathy may be

**ABBREVIATIONS** ASA = American Society of Anesthesiologists; LE = lumbar endoscopic; LSS = lumbar spinal stenosis; MCID = minimally clinically important difference; MIS = minimally invasive surgery; ODI = Oswestry Disability Index; PI-LL = pelvic incidence–lumbar lordosis; ULBD = unilateral laminotomy for bilateral decompression; VAS = visual analog scale.

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candidates for decompression-only procedures; however, even in this cohort, controversy remains, given early experiences with poor outcomes and curve progression following traditional open laminectomies.<sup>26,28</sup>

Minimally invasive decompressive techniques seek to minimize collateral damage and preserve the posterior elements with the purported advantage of preventing iatrogenic instability and curve progression associated with open techniques.<sup>3,22,52</sup> While minimally invasive surgery using tubular-based unilateral laminotomy for bilateral decompression (MIS-ULBD) has been shown to be a clinically effective procedure in the treatment of a subset of LSS patients with degenerative scoliosis,<sup>23,37,38</sup> there is a paucity of data on the effectiveness of the lumbar endoscopic ULBD (LE-ULBD) technique for this same cohort.

Endoscopic spine surgery represents the evolution of minimally invasive surgical access to spinal pathology. Multiple studies<sup>27,34,40,45,49,56</sup> have demonstrated that endoscopic lumbar decompression in the setting of LSS provides equivalent outcomes to microsurgical or tubular techniques with shorter hospital stay and less collateral tissue injury.<sup>2,40,41,47</sup> The purpose of this study was to evaluate and compare the clinical efficacy of LE-ULBD and MIS-ULBD decompression in patients with LSS and coexisting degenerative deformity.

## Methods

### Patient Selection

All participating patients provided written informed consent prior to undergoing the procedures as detailed. Collection of standard perioperative and postoperative outcome data are routinely performed as part of the University of Washington Spine Care Quality Initiative. Our prospectively collected database was retrospectively queried for ULBD performed with either a working channel endoscope (LE-ULBD) or an MIS technique using tubular retractors and the microscope (MIS-ULBD).<sup>11</sup> Forty-five consecutive procedures were performed at the University of Washington between September 2014 and February 2017 by a single surgeon (C.P.H.). Conservative therapy in patients described in the current cohort, including at least 6 weeks of physical therapy, nonsteroidal antiinflammatory drugs, or epidural steroid injections, had failed. Only patients with LSS with coexisting stable degenerative spondylolisthesis (slip  $\geq 3$  mm) or degenerative lumbar scoliosis ( $\geq 10^\circ$  coronal Cobb angle) were included in our study cohort. Patients were excluded if they had dynamic instability ( $> 3$  mm motion on flexion/extension radiographs), severe clinical sagittal imbalance (unable to stand upright), primary disc herniation, or a sequestered disc fragment.

Standard patient demographics, operative details, clinical outcomes, complications, and preoperative imaging measurements were recorded, including disc height, Cobb angle, static spondylolisthesis slip distance and grades, axial facet angle, pelvic incidence, and lumbar lordosis. Outcomes were quantified using visual analog scale (VAS) and Oswestry Disability Index (ODI) scores<sup>19</sup> at 2 weeks, 3 months, and at 1 year. With respect to ODI scoring, we regarded the minimally clinically important dif-

ference (MCID)<sup>8,25,29</sup> to be 12 absolute points, and for VAS the MCID was 3 points.<sup>20,21,29</sup>

### Surgical Technique

We used a previously described technique for MIS-ULBD<sup>11</sup> consisting of a traditional unilateral MIS approach through tubular retractors that can be used for bilateral decompression. The full-endoscopic ULBD technique has been previously described by the senior author.<sup>9</sup> Briefly, sequential dilators are used to create a tubular path in which a beveled working cannula is placed, followed by a working-channel spinal endoscope (iLESSYS Delta, Joimax, Vertebris stenosis, RIWOSpine). Under direct endoscopic visualization, a high-speed diamond burr is used to create an ipsilateral laminotomy extending to the base of the spinous process, exposing the ligamentum flavum. The ligamentum flavum is then resected piecemeal using micropunches and Kerrison rongeurs to enter the epidural space. The contralateral lamina and medial facet are then undercut using the burr, and the ligamentum flavum is excised to decompress the contralateral traversing nerve root. The ipsilateral traversing nerve root is then decompressed by rotating the optics of the endoscope, allowing full visualization and access for medial facetectomy and resection of the ligamentum flavum. Patients in both cohorts were placed under general anesthesia and were permitted to leave the hospital the day of surgery; however, patients with medical comorbidities requiring close postoperative monitoring and patients older than 70 years were admitted to the hospital for observation.

### Statistical Analysis

Continuous variables are presented as the mean  $\pm$  SD. Independent continuous variables were compared using a t-test. Categorical variables were compared using the chi-square test;  $p < 0.05$  was considered significant. Statistical calculations were carried out using IBM SPSS version 24 for Mac (IBM Corp.).

## Results

The current study includes 45 patients with LSS with an average follow-up period of 12 months. Final follow-up data were available for 87% of our entire cohort. There were 19 patients who underwent MIS-ULBD and 26 patients who underwent LE-ULBD. Preoperative demographic and clinical characteristics, listed in Table 1, demonstrated no significant differences between cohorts. Based on the American Society of Anesthesiologists (ASA) physical status classification system, 59% of patients across cohorts were categorized as having severe systemic disease (ASA class III). Prior to surgery, patients in both cohorts were classified as severely disabled as indicated by a mean ODI score of  $50.6 \pm 13.0$ .

The decision to treat each patient with MIS or endoscopic technique was primarily related to equipment availability rather than surgical preference. All patients in the MIS cohort underwent surgery between September 2014 and June 2016, with the majority treated in 2015. After endoscopy equipment was adopted at the University of Washington, the endoscopic technique was performed al-

**TABLE 1. Patient demographics and preoperative clinical data**

	Overall	MIS-ULBD	LE-ULBD	p Value
No. of patients	45	19	26	
Mean age, yrs (SD)	68.5 (10.3)	66.6 (8.0)	69.9 (11.6)	0.171
Sex				
Male	24 (53%)	12 (63%)	12 (46%)	0.366
Female	21 (47%)	7 (37%)	14 (54%)	
Mean BMI (SD)	30.1 (7.8)	28.3 (4.6)	31.4 (9.3)	0.368
ASA class				
I	2 (5%)	0 (0%)	2 (8%)	0.934
II	16 (36%)	8 (42%)	8 (32%)	
III	26 (59%)	11 (58%)	15 (60%)	
IV	0 (0%)	0 (0%)	0 (0%)	
Mean preop back VAS score (SD)	6.3 (2.7)	7.1 (2.2)	5.8 (2.9)	0.187
Mean preop leg VAS score (SD)	6.5 (2.3)	6.3 (2.4)	6.6 (2.3)	0.755
Mean preop ODI (SD)	50.6 (13.0)	46.6 (16.0)	52.8 (10.7)	0.125
No. of levels				
Mean (SD)	1.7 (0.8)	1.8 (0.9)	1.6 (0.7)	0.790
Single	20 (44%)	8 (42%)	12 (46%)	>0.99
Multiple	25 (56%)	11 (58%)	14 (54%)	
2	21 (84%)	8 (73%)	13 (93%)	0.434
3	2 (8%)	2 (18%)	0 (0%)	
4	2 (8%)	1 (9%)	1 (7%)	
Surgical level (multiple possible)				
T12–L1	1 (2%)	0 (0%)	1 (4%)	>0.99
L1–2	4 (9%)	1 (5%)	3 (12%)	0.627
L2–3	13 (29%)	6 (32%)	7 (27%)	0.751
L3–4	23 (51%)	11 (58%)	12 (46%)	0.550
L4–5	28 (62%)	13 (68%)	15 (58%)	0.543
L5–S1	6 (13%)	1 (5%)	5 (19%)	0.222
Pathology				
LSS only	36 (80%)	16 (84%)	20 (77%)	0.407
LSS + disc herniation	5 (11%)	3 (16%)	2 (8%)	
LSS + synovial cyst	2 (4%)	0 (0%)	2 (8%)	
LSS + foraminal stenosis	2 (4%)	0 (0%)	2 (8%)	
Presence of deformity				
Spondylolisthesis only	6 (13%)	2 (11%)	4 (15%)	0.158
Scoliosis only	16 (36%)	4 (21%)	12 (46%)	0.877
Scoliosis w/ spondylolisthesis	23 (51%)	13 (68%)	10 (38%)	
Mean PI-LL mismatch, ° (SD)	15.6 (11.5)	14.4 (9.4)	16.6 (13.3)	
Mean EBL, mL (SD)	17.3 (16.7)	30.0 (18.9)	3.1 (5.0)	<b>&lt;0.001</b>
Mean length of stay, days (SD)	1.2 (1.1)	1.7 (1.2)	0.9 (0.8)	<b>0.014</b>

EBL = estimated blood loss.

Values are presented as the number of patients (%) unless stated otherwise. Boldface type indicates statistical significance by Mann-Whitney and Fisher's exact test as appropriate.

most exclusively from June 2016 until the endpoint of the study in February 2017. One important exception to this was a tendency to perform the MIS technique in the case of 3-level decompressions, which were rare.

Patient operative data are listed in Table 1. The total number of operative levels was 75, with 32 operative levels

in the MIS-ULBD cohort and 43 operative levels in the LE-ULBD cohort. Within the MIS-ULBD cohort, 42% of patients underwent 1-level surgery and 58% of patients underwent multilevel surgery. Within the LE-ULBD cohort, 46% of patients underwent 1-level surgery and 54% of patients underwent multilevel surgery. The majority of

TABLE 2. Radiographic data by subgroup

	Overall	MIS-ULBD	LE-ULBD	p Value
Spondylolisthesis subgroup				
Mean PI, ° (SD)	59.5 (12.2)	58.0 (14.8)	60.6 (10.1)	0.373
Mean LL, ° (SD)	49.0 (10.1)	51.0 (11.2)	46.9 (8.9)	0.306
Mean PI-LL mismatch, ° (SD)	13.6 (10.7)	13.6 (11.3)	13.7 (10.6)	0.979
Mean disc height, mm (SD)	9.2 (3.2)	9.2 (3.3)	9.3 (3.1)	0.594
Mean slip measurement, mm (SD)	6.2 (2.8)	6.5 (3.4)	5.9 (2.1)	0.941
Mean axial facet angle, ° (SD)	47.9 (15.5)	48.3 (12.8)	47.5 (18.6)	0.642
Scoliosis subgroup				
Mean Cobb angle, ° (SD)	15.9 (7.6)	15.6 (6.0)	16.1 (8.7)	>0.99
Mean PI, ° (SD)	60.0 (12.3)	62.5 (14.9)	58.5 (10.6)	0.674
Mean LL, ° (SD)	46.9 (11.1)	49.7 (10.9)	44.9 (11.0)	0.171
Mean PI-LL mismatch, ° (SD)	14.9 (11.8)	14.9 (10.8)	15.0 (12.7)	0.827
Mean disc height, mm (SD)	9.0 (3.0)	9.6 (2.7)	8.7 (3.1)	0.204
Mean axial facet angle, ° (SD)	46.4 (15.4)	48.8 (12.4)	44.7 (17.2)	0.580
Lateral listhesis, no.				
None	27 (41%)	12 (44%)	15 (38%)	0.610
Positive	39 (59%)	15 (56%)	24 (62%)	
Mean, mm (SD)	6.1 (2.4)	6.1 (1.8)	6.0 (2.7)	0.945

Statistical significance by Mann-Whitney (patients) and mixed-effects rank-linear and logistic regression (surgery levels).

patients in both groups were treated for central and lateral recess stenosis; 9 patients were treated for additional pathology including nonsequestered disc herniation (11%), synovial cyst (4%), and foraminal stenosis (4%). The most common surgical level was L4–5, with 62% of patients undergoing surgery at this level. Average estimated blood loss was significantly less in the LE-ULBD cohort than in the MIS-ULBD cohort ( $p < 0.001$ ). Average hospital length of stay was significantly greater in the MIS-ULBD cohort ( $1.7 \pm 1.2$  days) than in the LE-ULBD cohort ( $0.9 \pm 0.8$  days) ( $p = 0.014$ ).

With regard to presence of deformity, 13% of our cohort had spondylolisthesis with no coexisting scoliosis, 36% of our cohort had scoliosis with no coexisting spondylolisthesis, and 51% had the presence of both spondylolisthesis and scoliosis. There were no significant differences in presence or degree of deformity across cohorts. Preoperative radiographic data are listed in Tables 2 and 3. Patients with scoliosis presented with an average Cobb angle of  $15.9^\circ \pm 7.6^\circ$ , and 59% of patients demonstrated lateral listhesis (mean  $6.1 \pm 2.4$  mm). Patients with spondylolisthesis presented with an average slip of  $6.2 \pm 2.8$  mm. The average disc height was  $9.2 \pm 3.2$  mm, and the average axial facet angle was  $47.9^\circ \pm 15.5^\circ$ . The average pelvic incidence–lumbar lordosis (PI-LL) mismatch for the entire cohort was  $15.6^\circ \pm 11.5^\circ$ .

Patient-reported outcomes at all follow-up intervals are reported in Tables 3 and 4. Patients in the total cohort experienced significant improvement in VAS back pain, VAS leg pain, and ODI when comparing preoperative values to all postoperative time points ( $p < 0.001$ , Fig. 1). When comparing outcomes between the MIS-ULBD and LE-ULBD, the endoscopic cohort demonstrated significantly better early ODI scores ( $p = 0.024$ ); however, there

were no significant differences at later time points. The percentage of patients reaching MCID for VAS leg pain in the MIS-ULBD and LE-ULBD groups was 82% and 95%, respectively (Table 5). The percentage of patients reaching MCID for ODI in the MIS-ULBD group and LE-ULBD group was 86% for both groups. There was no significant difference in the percentage of patients reaching MCID for both outcome measures.

The number of total adverse events experienced can be found in Table 5. An adverse event was defined as any perioperative medical event (any medical event requiring medical consultation or delaying discharge), intraoperative complications such as incidental durotomy, infection, or any reoperation within the follow-up period. The total number of perioperative medical events for patients in the MIS-ULBD cohort was greater than those experienced in the LE-ULBD cohort (5 [26%] vs 2 [8%] events); however, this difference was not statistically significant. Perioperative medical complications included urinary retention ( $n = 4$ ), syncope ( $n = 1$ ), stroke ( $n = 1$ ), and laboratory abnormalities requiring medical consultation ( $n = 1$ ). Two patients (11%) in the MIS-ULBD group and 0 patients (0%) in the LE-ULBD group sustained an incidental durotomy ( $p = 0.173$ ). There were no infections in either group.

Two patients requiring reoperation, with a total reoperation rate of 4%. The reoperation rate at 1 year for the MIS-ULBD cohort was 11% versus 0% in the LE-ULBD cohort, although this was not statistically significant ( $p = 0.173$ ). All reoperations in the MIS-ULBD cohort occurred at an average time to reoperation of 6 months. All patients who required reoperation had recurrent leg symptoms at the index level and were treated with endoscopic transforaminal decompression. When looking at all adverse events, including all perioperative complications and

TABLE 3. Outcome over time

	Overall						MIS-ULBD						LE-ULBD					
	ΔFrom Preop			Mean Score	p Value	95% CI	ΔFrom Preop			Mean Score	p Value	95% CI	ΔFrom Preop			Mean Score	p Value	95% CI
	Raw	Mod	95% CI				Raw	Mod	95% CI				Raw	Mod	95% CI			
VAS back																		
Preop	6.34			7.14						5.79								
2 wks	-2.39	-2.32	-3.30 to -1.34	4.67	<0.001	-2.47	-2.34	-3.82 to -0.87	4.67	0.003	-2.31	-2.31	-3.63 to -0.99	3.48	0.001	-2.31	-2.31	-3.63 to -0.99
3 mos	-4.05	-4.02	-5.00 to -3.03	1.93	<0.001	-5.21	-5.12	-6.59 to -3.64	1.93	<0.001	-3.27	-3.29	-4.61 to -1.97	2.52	<0.001	-3.27	-3.29	-4.61 to -1.97
1 yr	-4.21	-4.17	-5.15 to -3.19	2.50	<0.001	-4.64	-4.58	-5.99 to -3.18	2.50	<0.001	-3.99	-3.94	-5.32 to -2.56	1.80	<0.001	-3.99	-3.94	-5.32 to -2.56
VAS leg																		
Preop	6.46			6.32					6.32					6.56				
2 wks	-4.04	-4.01	-4.99 to -3.03	2.47	<0.001	-3.86	-3.82	-5.41 to -2.24	2.47	<0.001	-4.17	-4.14	-5.42 to -2.87	2.39	<0.001	-4.17	-4.14	-5.42 to -2.87
3 mos	-4.65	-4.56	-5.54 to -3.58	1.53	<0.001	-4.79	-4.64	-6.23 to -3.06	1.53	<0.001	-4.56	-4.51	-5.79 to -3.24	2.00	<0.001	-4.56	-4.51	-5.79 to -3.24
1 yr	-4.65	-4.69	-5.67 to -3.71	2.22	<0.001	-4.10	-4.05	-5.54 to -2.56	2.22	<0.001	-5.11	-5.24	-6.57 to -3.91	1.45	<0.001	-5.11	-5.24	-6.57 to -3.91
ODI																		
Preop	50.6			46.6					46.6					52.8				
2 wks	-17.6	-16.4	-22.7 to -10.0	38.7	<0.001	-7.8	-7.1	-16.2 to -2.1	38.7	0.126	-23.8	-22.2	-30.9 to -13.6	29.1	<0.001	-23.8	-22.2	-30.9 to -13.6
3 mos	-30.9	-30.1	-36.6 to -23.6	15.1	<0.001	-31.5	-29.5	-38.7 to -20.2	15.1	<0.001	-29.8	-29.6	-38.4 to -20.7	23.0	<0.001	-29.8	-29.6	-38.4 to -20.7
1 yr	-29.6	-29.5	-35.9 to -23.1	22.1	<0.001	-24.5	-24.8	-33.7 to -15.9	22.1	<0.001	-32.9	-32.3	-41.3 to -23.3	19.9	<0.001	-32.9	-32.3	-41.3 to -23.3

Mod = modeled difference.

Boldface type indicates statistical significance by mixed-effects linear regression, unadjusted for other covariates. All statistically significant differences survived adjustment for multiple comparisons (Benjamini-Hochberg procedure, m = 36).

**TABLE 4. Effects of surgery group on outcome (over time)**

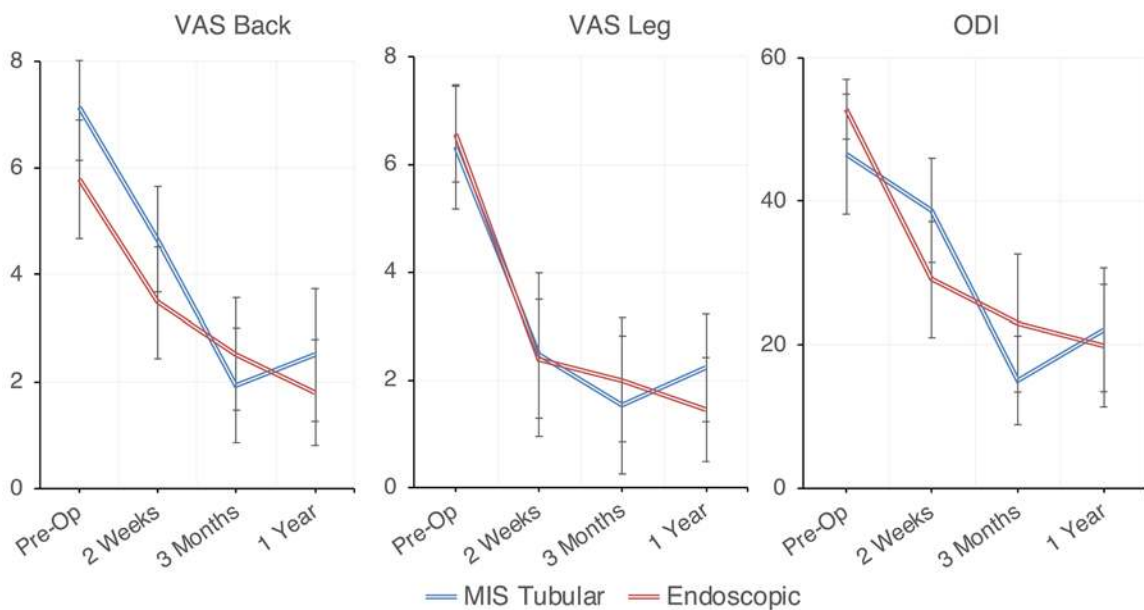
	Score		ΔFrom Preop			Model Estimates				
	MIS-ULBD	LE-ULBD	MIS-ULBD	LE-ULBD	Difference	LE-ULBD Effect	95% CI	p Value	Favor	
VAS back										
Preop	7.14	5.79								
2 wks	4.67	3.48	-2.47	-2.31	0.16	0.00	-1.99 to 2.00	0.997	MIS-ULBD	
3 mos	1.93	2.52	-5.21	-3.27	1.94	1.81	-0.18 to 3.80	0.075	MIS-ULBD	
1 yr	2.50	1.80	-4.64	-3.99	0.65	0.63	-1.35 to 2.60	0.531	MIS-ULBD	
VAS leg										
Preop	6.32	6.56								
2 wks	2.47	2.39	-3.86	-4.17	-0.31	-0.32	-2.33 to 1.69	0.754	LE-ULBD	
3 mos	1.53	2.00	-4.79	-4.56	0.23	0.14	-1.88 to 2.15	0.894	MIS-ULBD	
1 yr	2.22	1.45	-4.10	-5.11	-1.01	-1.20	-3.17 to 0.78	0.233	LE-ULBD	
ODI										
Preop	46.6	52.8								
2 wks	38.7	29.1	-7.8	-23.8	-15.9	-15.0	-28.0 to -2.0	<b>0.024</b>	LE-ULBD	
3 mos	15.1	23.0	-31.5	-29.8	1.7	0.1	-13.1 to 13.2	0.991	MIS-ULBD	
1 yr	22.1	19.9	-24.5	-32.9	-8.5	-7.5	-20.5 to 5.4	0.252	LE-ULBD	

Boldface type indicates statistical significance by mixed-effects linear regression, unadjusted for other covariates. No statistically significant differences after adjusting for multiple comparisons (Benjamini-Hochberg,  $m = 12$ ).

reoperations, the MIS-ULBD cohort was found to have a statistically significant greater number of adverse events ( $n = 8$ ) than the LE-ULBD cohort ( $n = 2$ ) ( $p = 0.010$ ). No patient experienced postoperative iatrogenic motor or sensory deficits.

A poor outcome was defined as any reoperation or failure to reach MCID for leg VAS and ODI score. Univariate

analyses were used to predict poor outcomes from preoperative radiographic data (Tables 6 and 7). There was a trend toward poor outcome with larger Cobb angles, larger disc heights, and more sagittally oriented facet angles; however, this was not statistically significant after adjusting for multiple comparisons. No other radiographic variables were found to be predictive of poor outcomes.



**FIG. 1.** Patients in the total cohort experienced significant improvement in VAS back pain, VAS leg pain, and ODI when comparing preoperative values to all postoperative time points ( $p < 0.001$ ). When comparing outcomes between the MIS-ULBD and LE-ULBD cohorts, the endoscopic cohort demonstrated significantly better early ODI scores ( $p = 0.024$ ); however, there were no significant differences at later time points. Means and SDs are shown.

**TABLE 5. Adverse events and MCID effects of surgery group on outcome (over time)**

	No. of Patients (%)			p Value
	Overall	MIS-ULBD	LE-ULBD	
<b>Adverse events</b>				
Any adverse event	10 (22)	8 (42)	2 (8)	<b>0.010</b>
Periop medical event	7 (16)	5 (26)	2 (8)	0.114
Intraop durotomy	2 (4)	2 (11)	0 (0)	0.173
Infection	0 (0)	0 (0)	0 (0)	
Reop	2 (4)	2 (11)	0 (0)	0.173
<b>MCID for VAS leg at 1 yr</b>				
No	4 (11)	3 (18)	1 (5)	0.326
Yes	32 (89)	14 (82)	18 (95)	
<b>MCID for ODI at 1 yr</b>				
No	5 (14)	2 (14)	3 (14)	>0.99
Yes	30 (86)	12 (86)	18 (86)	

Boldface type indicates statistical significance.

## Discussion

Surgical decompression without fusion has been well accepted as the optimal treatment for patients with uncomplicated LSS causing neurogenic claudication.<sup>54</sup> Clinical decision-making becomes more challenging when patients with LSS present with coexisting spondylolisthesis and/or degenerative scoliosis. The ongoing debate regarding decompression alone versus decompression with fusion in this specific cohort has largely been informed by data pertaining to decompression via conventional midline laminectomy. In their landmark controlled trial, Herkowitz and Kurz demonstrated a high failure rate in patients with spondylolisthesis after a conventional midline muscle-stripping laminectomy.<sup>33</sup> Consequently, this resulted in the widespread investigation of fusion with decompression for any patient with LSS and concomitant structural abnormalities. In the United States, 96% of patients with degenerative spondylolisthesis undergo fusion surgery as an adjunct to decompression,<sup>39</sup> and approximately 70% of patients with LSS and coexisting scoliosis undergo a fusion procedure.<sup>4</sup>

Fusion itself, however, can be complicated by pseudarthrosis<sup>18</sup> and adjacent-segment disease,<sup>44</sup> ultimately leading to loss of therapeutic sustainability over time. A large analysis of registry data showed that the addition of fusion surgery to decompression surgery for spinal stenosis doubled the risk of severe adverse events.<sup>14,16</sup> The potential risks and complications are significantly amplified when the alternative to decompression includes long hardware constructs, with some series showing complication rates greater than 50%.<sup>55</sup>

Based on the available literature, there is considerable variability in outcomes following decompression to address stenosis in the setting of degenerative scoliosis and spondylolisthesis. Several early studies have reported high rates of progressive deformity and failure of conventional laminectomy in patients with deformity and symptomatic stenosis.<sup>1,6,17,24,36,48</sup> More recent literature regarding con-

**TABLE 6. Univariate prediction of poor outcome from radiographic data**

	Poor Outcome*		
	OR	95% CI	p Value
<b>Patient characteristics</b>			
Spondylolisthesis	1.39	0.18–17.4	>0.99
Scoliosis	0.60	0.06–8.55	0.958
Cobb angle (per 5°)	0.67	0.36–1.16	0.166
<b>Level characteristics</b>			
Disc height (per mm)	1.19	0.92–1.58	0.186
Axial facet angle (per 5°)	1.17	0.93–1.51	0.188
Lateral listhesis	0.56	0.11–2.70	0.614

Statistical significance by exact logistic regression. No statistically significant differences after adjusting for multiple comparisons (Benjamini-Hochberg,  $m = 6$ ).

\* Poor outcome defined as any of 1) reoperation, 2) no MCID for VAS leg, or 3) no MCID for ODI.

ventional laminectomy has painted a conflicting picture. One study found lower functional outcome scores and higher complication rates (56% vs 10%) in patients undergoing large construct fusion with decompression than in patients receiving decompression alone; however, patients in the decompression group were less likely to respond favorably to questionnaires regarding patient satisfaction than those in the fusion groups.<sup>53</sup> Brodke et al.<sup>12</sup> conducted a retrospective review comparing 3 treatment arms for radiculopathy in the setting of deformity. Ninety consecutive patients with a minimum 2-year follow-up were treated for LSS with associated deformity (mean Cobb angle 17°) with interspinous device placement, laminectomy alone, or laminectomy and short-segment fusion. The index-level reoperation rates were 33.3%, 8.3%, and 0%, respectively; however, the reoperation rate due to adjacent-segment disease was highest in the fusion group (24.4%). The authors determined that conventional laminectomy alone had the highest rate of survival. One retrospective study found that in 50 patients who underwent traditional open decompression procedures in the setting of mild to moderate deformity with a mean follow-up 2.8 years, the average curve progression was 3.4° with a mean reoperation rate of 10%.<sup>35</sup> These studies highlight the lack of certainty regarding the role of conventional laminectomy and potential iatrogenic instability in LSS patients with coexisting deformity, with reoperation rates ranging from 8% to 37%. These results must also be taken into the context of the natural progression of degeneration that occurs with aging.

The advent of minimally invasive, midline-sparing techniques have revisited the validity of performing fusion in all patients who have a deformity associated with their symptomatic stenosis. Numerous biomechanical studies<sup>30,31</sup> have demonstrated that minimally invasive techniques help maintain spinal stability when compared with more conventional open techniques, presumably by sparing osseoligamentous structures. A recent study based on finite-element analysis found that endoscopic decompression has no negative impact on mechanical stability.<sup>46</sup> These less-invasive techniques are particularly useful in

**TABLE 7. Univariate prediction of reoperation and inability to reach MCID from radiographic data**

	Reop			No MCID for VAS Leg			No MCID for ODI		
	OR	95% CI	p Value	OR	95% CI	p Value	OR	95% CI	p Value
<b>Patient characteristics</b>									
Spondylolisthesis	1.36	0.16 to ∞	0.820	0.40	0.03 to 6.34	0.712	3.09	0.51 to ∞	0.327
Scoliosis	0.37	0.04 to ∞	>0.99	1.12	0.17 to ∞	0.931	0.18	0.01 to 2.95	0.278
Cobb angle (per 5°)	0.75	0.26 to 1.76	0.582	0.91	0.46 to 1.68	0.801	0.52	0.23 to 1.02	0.058
PI-LL mismatch	1.02	0.89 to 1.14	0.698	0.90	0.67 to 1.07	0.383	0.96	0.82 to 1.07	0.554
<b>Level characteristics</b>									
Disc height (per mm)	1.14	0.78 to 1.78	0.534	1.01	0.74 to 1.40	>0.99	1.99	1.20 to 4.03	0.003
Slip (per mm)	0.82	0.37 to 1.47	0.663	0.84	0.40 to 1.49	0.735	0.76	0.43 to 1.16	0.250
Axial facet angle (per 5°)	1.61	0.96 to 3.17	0.078	0.89	0.67 to 1.19	0.405	1.35	0.95 to 2.09	0.108
Lateral listhesis	3.50	0.52 to ∞	0.293	0.21	0.00 to 2.33	0.311	0.15	0.00 to 1.62	0.154
Lateral listhesis (per mm)	0.95	0.57 to 1.59	0.852	0.83	0.22 to 2.11	0.733	0.35	0.01 to 1.29	0.182

Statistical significance by exact logistic regression, unadjusted for within-subject correlations (due to low event counts). No statistically significant differences after adjusting for multiple comparisons (Benjamini-Hochberg,  $m = 30$ ).

patients with coexisting deformity, whereby removal of bony elements and soft-tissue disruption have the potential to exacerbate existing structural instability and cause recurrence of symptoms.

Kelleher et al. conducted a retrospective review of 75 patients undergoing tubular MIS-ULBD for focal spinal stenosis with or without coexisting scoliosis (mean Cobb angle 14°) with a mean 47.5-month follow-up.<sup>38</sup> The authors reported significant improvements in ODI scores in patients with deformity with no significant progression of scoliosis; however, there was a 25% reoperation rate, with 50% of these failures in patients with concurrent lateral listhesis. Conversely, a recent 2017 prospective study with 2-year follow-up compared outcomes in 207 patients with spinal stenosis with or without coexisting scoliosis (mean Cobb angle 14°) following tubular MIS-ULBD<sup>37</sup> and found significant increases in functional outcomes in all patients with an 8% reoperation rate, which was associated with preoperative scoliotic disc wedging (Cobb angle  $\geq 3^\circ$ ) and lateral listhesis. Our tubular MIS-ULBD cohort was found to have a reoperation rate of 11%, which is consistent with rates reported in the literature. Interestingly, no patients in our endoscopic cohort underwent reoperation within the 1-year follow-up period.

To our knowledge, there are limited data regarding the use of decompressive endoscopic spine techniques to treat lumbar spinal stenosis in the setting of deformity and spondylolisthesis. Telfeian et al. reported a series of 4 patients who underwent transforaminal endoscopic decompression to treat unilateral radiculopathy from a disc herniation in the setting of deformity with lateral listhesis.<sup>51</sup> Madhavan et al. conducted a retrospective analysis of 16 patients with moderate coronal deformity (mean Cobb angle 16.8°) who underwent endoscopic transforaminal decompression for unilateral radiculopathy with a mean 7.5-month follow-up.<sup>42</sup> All patients had significant improvement in patient reported outcome scores, with only 1 patient requiring reoperation at 1 week for reherniation.

Our study represents the first and largest series investigating interlaminar endoscopic decompression in pa-

tients with LSS in the setting of degenerative scoliosis and spondylolisthesis. Our results show that endoscopic decompression is a safe and effective alternative for this patient cohort, as there were significant improvements in all patient-reported outcome measures with a minimum of complications reported at 1 year. Patients in the endoscopic cohort achieved MCID for leg pain VAS score in 95% of cases compared with 82% of patients achieving MCID in the MIS-ULBD cohort, which, while not significantly different, indicates likely equipoise across techniques. Furthermore, while complication rates were very low in both cohorts, we feel that endoscopic decompression has a more favorable risk profile than MIS-ULBD with fewer overall adverse events and a lower reoperation rate. Most adverse events experienced in the MIS cohort consisted of urinary retention, which, while a relatively minor complication, can contribute to increased hospital length of stay and should be considered meaningful. Endoscopic decompression also results in significantly faster recovery, reflected by a shorter hospital length of stay and more rapid improvement in ODI during early follow-up.

Our univariate analysis was not able to identify any preoperative factors to predict poor outcome or reoperation. Previous studies, however, postulated that preoperative scoliotic disc wedging (Cobb angle  $\geq 3^\circ$ ) and lateral listhesis<sup>37,38</sup> are associated with reoperation, while spur formation on the concave side of scoliotic curves may be a protective factor in curve progression.<sup>35</sup> Blumenthal et al. reported that in patients with degenerative grade I lumbar spondylolisthesis who underwent conventional laminectomy, a facet angle  $> 50^\circ$  was associated with a 39% rate of reoperation, and a disc height  $> 6.5$  mm was associated with a 45% rate of reoperation.<sup>10</sup> While our patient population demonstrated a trend toward worse outcomes with increasing disc height, Cobb angle, and facet angle measurements, there were no statistically significant radiographic parameters that predicted poor outcomes after adjusting for multiple comparisons.

Although sagittal spinal parameters are critical elements in optimizing outcomes, the inability to restore



sagittal alignment in patients undergoing decompression for spinal stenosis in the setting of degenerative scoliosis (without major instability) has not been shown to have an impact on outcomes.<sup>5</sup> Our patient cohort represents patients with mild to moderate coronal deformity (mean Cobb angle 15.9°) and minimal sagittal imbalance (PI-LL mismatch = 15.6°). Patients with clinically significant deformity and sagittal imbalance are unlikely to benefit from these minimally invasive techniques.

While we present evidence that full-endoscopic decompression is a viable alternative to current treatment options, our report has several limitations. This study is a retrospective review of prospectively collected data in a relatively small patient cohort with 1-year follow-up. Our patient selection was not randomized but rather reflects an evolution in practice, which may introduce selection bias. Patients who underwent tubular MIS decompression in our study achieved VAS leg pain score reductions (−4.1), which is comparable with those published in the literature at ≥ 1-year follow-up (−4.6).<sup>3</sup> The reduction in ODI score in our MIS group was 24.5, with 86% of these patients achieving an MCID in ODI score. This is comparable to previously reported outcomes after MIS-ULBD (ODI score reduction: 16.4; proportion of MCID: 54.8%<sup>3</sup>). Therefore, we are confident that our tubular MIS decompression outcomes represent an appropriate reference for comparison to the endoscopic decompression cohort.

We anticipate that with longer follow-up, additional patients in the endoscopic group may require reoperation due to the degenerative cascade. We have not routinely performed imaging in patients without new symptomatology and are thus unable to report the radiographic follow-up for our study group; however, we emphasize that clinical outcomes and not radiographic measurements were used as the basis by which to draw conclusions. Our results may not apply to patients who suffer from symptomatic imbalance with progressive deformity and inability to stand or walk. These patients were excluded from the present study, which might lead to a selection bias; however, the focus of this analysis was on patients whose predominant complaints are related to lumbar spinal stenosis in the setting of mild to moderate deformity.

## Conclusions

Full-endoscopic decompression represents a promising treatment option for patients with lumbar spinal stenosis and concurrent mild to moderate degenerative scoliosis and spondylolisthesis. While the decision to perform a decompression, short-segment, or long-segment fusion will ultimately depend on a variety of patient factors and surgeon preference, the endoscopic approach offers an effective option with a favorable risk profile in the appropriately selected patient. Future research is needed to determine the long-term benefits and cost-effectiveness of endoscopic decompression when treating this particular patient cohort.

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### Disclosures

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