

Minimally Invasive Surgery: Lateral Approach Interbody Fusion

Results and Review

Jim A. Youssef, MD,* Paul C. McAfee, MD, MBA,† Catherine A. Patty, MS, CCRC,*
Erin Raley, BA,* Spencer DeBauche, BS,* Erin Shucosky, RN,† and Liana Chotikul, RN†

Study Design. A retrospective review of patients treated at 2 institutions with anterior lumbar interbody fusion using a minimally invasive lateral retroperitoneal approach, and review of literature.

Objective. To analyze the outcomes from historical literature and from a retrospectively compiled database of patients having undergone anterior interbody fusions performed through a lateral approach.

Summary of Background Data. A paucity of published literature exists describing outcomes following lateral approach fusion surgery.

Methods. Patients treated with extreme lateral interbody fusion (XLIF) were identified through retrospective chart review. Treatment variables included operating room (OR) time, estimated blood loss (EBL), length of hospital stay (LOS), complications, and fusion rate. A literature review, using the National Center for Biotechnology Information databases PubMed/MEDLINE and Google Scholar, yielded 14 peer-reviewed articles reporting outcomes scoring, complications, fusion status, long-term follow-up, and radiographic assessments related to XLIF. Published XLIF results were summarized and evaluated with current study data.

Results. A total of 84 XLIF patients were included in the current cohort analysis. OR time, EBL, and length of hospital stay averaged 199 minutes, 155 mL, and 2.6 days, respectively, and perioperative and postoperative complication rates were 2.4% and 6.1%. Mean follow-up was 15.7 months. Sixty-eight patients showed evidence of solid arthrodesis and no subsidence on computed tomography and flexion/extension radiographs. Results were within the ranges of those in the literature. Literature review identified reports of significant improvements in clinical outcomes scores, radiographic measures, and cost effectiveness.

Conclusion. Current data corroborates and contributes to the existing body of literature describing XLIF outcomes. Procedures are generally performed with short OR times, minimal EBL, and few complications. Patients

recover quickly, requiring minimal hospital stay, although transient hip/thigh pain and/or weakness is common. Long-term outcomes are generally favorable, with maintained improvements in patient-reported pain and function scores as well as radiographic parameters, including high rates of fusion.

Key words: XLIF, anterior lumbar interbody fusion, ALIF, MIS, clinical outcomes. **Spine 2010;35:S302–S311**

Of the US population, an estimated 80% will experience some form of back pain in their lifetime and the frequency of active back pain is estimated to be 26% of the population at any given time.¹ In some instances, these symptoms are secondary to degenerative spinal conditions, broadly labeled degenerative disc disease, which often includes disc prolapse or herniation, spinal stenosis, and other degenerative conditions. In patients with prolonged, severe symptoms and/or instability, lumbar spondylotic disease, disc degeneration or herniation, facet degeneration, spondylolisthesis, stenosis, or scoliosis, lumbar fusion has been shown to be both clinically and cost effective.^{2–9}

Conventional surgical approaches for lumbar fusion, despite long-term clinical efficacy, have been associated with high morbidities that can offset the benefits of intervention.¹⁰ Approach-related morbidities include vascular complications in anterior lumbar interbody fusion,^{11,12} and neural complications in posterior and transforaminal lumbar interbody fusion (PLIF and TLIF).^{13–15} The plane of approach dictates the anatomy that must be traversed for access to the spine, and the extent of exposure influences blood loss, infection rates, and length of postoperative recovery. Open posterior approaches for fusion and supplemental internal fixation that require extensive dissection of paraspinal musculature can result in permanent erector spinae denervation and loss of function.^{16–18} Open lumbar spine surgeries are often accompanied by incisional pain,¹⁹ with increased rates of postoperative infection²⁰ compared to minimally invasive techniques.²⁰ With the introduction of endoscopic and mini-open techniques for anterior column fusion and percutaneous posterior pedicle screw technology, the field of spine surgery has moved decidedly toward lessening approach-related morbidities through the use of minimally invasive techniques.

Mini-open approaches for lumbar interbody fusion have shown early promise in minimizing procedural morbidities with small incisions, blunt dissection, and

From the *Durango Orthopedic Associates, Spine Colorado, Durango, CO; and †Spine and Scoliosis Center, St. Josephs Hospital, Townson, MD.

Acknowledgment date: August 10, 2010. First revision date: September 28, 2010. Second revision date: October 15, 2010. Acceptance date: October 15, 2010.

The device (s)/drug (s) that is/are the subject of this manuscript is/are not FDA-approved for this indication and is/are not commercially available in the United States.

No funds were received in support of this work. One or more of the author (s) has/have received or will receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this manuscript: e.g., honoraria, gifts, consultancies, royalties, stocks, stock options, decision making position.

Address correspondence and reprint requests to Jim A. Youssef, MD, Durango Orthopedic Associates, Spine Colorado, 1 Mercado Street, Suite 200, Durango, CO 81301; E-mail: jyoussef@spinecolorado.com

direct visualization, with equal or improved long-term clinical and radiographic efficacy.^{18,21–27} The focus of this report is extreme lateral interbody fusion (XLIF; NuVasive, Inc., San Diego, CA). XLIF is performed through a lateral, retroperitoneal, transpsoas approach to the anterior column, and uses real-time directional neuromonitoring to ensure safe passage through the psoas muscle, avoiding the nerves of the lumbar plexus.²⁸ The benefits of the lateral approach used in XLIF, compared with anterior and posterior approaches, include the avoidance of vascular, visceral, and sexual dysfunction complications sometimes experienced in open anterior procedures, and paraspinous denervation, dural tear, and neural injuries in posterior approaches, while also allowing for a broad discectomy and placement of a large footprint graft. Additionally, the anterior and posterior longitudinal ligaments remain intact, providing inherent stability during the formation of bone in fusion.

The primary objective of the current work was to perform a review of the available XLIF literature, with emphasis on those publications including complication reporting and/or radiographic or functional clinical outcomes. The secondary objective of this work was to present the findings of a retrospective review of outcomes in patients treated with XLIF at 2 institutions for degenerative lumbar conditions, relative to the literature review.

■ Methods

Review of the Published Literature

A review of indexed medical journals was undertaken using the National Center for Biotechnology Information (NCBI) databases PubMed/MEDLINE. Additional publications published in peer-reviewed, nonindexed journals were found using www.scholar.google.com. The following keywords were used: XLIF, extreme, lateral, interbody, fusion, transpsoas, approach. Reports that included outcomes scoring, including visual analog scale (VAS), Oswestry disability index (ODI), complication rates, fusion status, long-term follow-up, and radiographic assessments were included in the review. Anatomic descriptions, technical reports, or case studies with limited outcomes data were not included. This narrowed the literature review to 14 original lateral approach publications.^{29–42}

Personal Experience

Data were retrospectively compiled from 2 sites, identifying all consecutive patients who underwent an XLIF procedure from 2004 to 2010. Patients were grouped and analyzed based on whether they underwent a single-approach anterior XLIF procedure (XLIF-only group) or XLIF with supplemental posterior spinal fusion (XLIF/PSF group). Indications for supplemental posterior instrumentation included degenerative scoliosis and spondylolisthesis. Anterior instrumentation included interbody implants (CoRoent XL, NuVasive, Inc., San Diego, CA) without internal fixation, a tabbed interbody implant with vertebral screws (CoRoent XL-F, NuVasive, Inc.), or an interbody implant with adjuvant titanium lateral plate using vertebral body bolts/screws (XLP, NuVasive, Inc.). Posterior spinal fusion, when performed, included the use of segmental pedicle screw fixation (various manufacturers). Posterior spinal fusion

was performed through an open technique if decompression was needed. If the diagnosis included spondylolisthesis and a decompression was not needed, posterior instrumentation was performed through percutaneous access. Both anterior and posterior fusions were grafted using bone morphogenetic protein (BMP) (INFUSE, Medtronic-Sofamor Danek, Memphis, TN) in conjunction with allograft.

Variables collected in the chart review included baseline comorbidities, operating room time, estimated blood loss (EBL), length of hospital stay (LOS), and peri- and postoperative complications. Perioperative complications were defined as complications occurring from the time of hospitalization to the time of discharge. Postoperative complications were any relevant conditions or events that occurred after the discharge period to final follow-up. At approximately 1-year after surgery, computed tomography (CT), anterior/posterior, lateral neutral, and lateral flexion/extension radiographs were reviewed to assess the progression of fusion, defined as bridging bone between the involved vertebral endplates (for interbody fusion) or transverse processes (for posterolateral fusion).⁴³

■ Results

A total of 84 patients underwent an XLIF procedure at the 2 contributing institutions from 2004 to 2010. Two patients were lost to follow-up. Diagnoses included combinations of spondylosis (n = 18), spondylolisthesis (n = 8), scoliosis (n = 34), adjacent segment disease (n = 22), spinal stenosis (n = 10), degenerative disc disease (n = 4), herniated nucleus pulposus (n = 4), trauma (n = 1), and tumor (n = 1). Total levels treated were 137, or an average of 1.6 levels per patient (Table 1). Overall, mean EBL was 155 mL (range, 20–1050 mL) and no transfusions were required. Operative time averaged 199 (range, 64–538) minutes. The mean LOS was 2.6 (range, 1–10) days.

The XLIF/PSF group had a longer surgical time (277 vs. 142 minutes; $P < 0.0001$) and increased mean EBL (245 vs. 81 mL; $P < 0.0001$) compared to the XLIF-only group, as expected, due to the supplemental posterior procedure. The average LOS was less for the XLIF-only group as compared to the XLIF/PSF group: (2.1 vs. 3.3 days; $P = 0.0020$).

Two patients (2.4%) experienced perioperative complications. One patient developed a pulmonary artery embolism as well as right ventricular clot intraoperatively. Another patient experienced an incidental durotomy during the posterior procedure, which was re-

Table 1. Treatment Details of Current Study Cohort

Total N	Levels/ Procedure	Total N/ Level	XLIF-Only Stand-Alone		XLIF-Only With Lateral Plate		XLIF/PSF	
			n	n/Level	n	n/Level	n	n/Level
84	1 level	45	15	9	31	25	38	11
	2 level	25		4		4		17
	3 level	14		2		2		10

N indicates number of patients; XLIF, extreme lateral interbody fusion; PSF, posterior spinal fusion.

Table 2. Complications Occurring in the Follow-up Period

Complication	Resolution/Intervention
Non-displaced bilateral pedicle fracture (1)	Braced
Ipsilateral psoas weakness (–5/5) and numbness (1)	Resolved 7 wk postoperatively
Mild endplate fracture (1)	Braced
Vertebral body fracture (1)	Revision corpectomy
Subsidence of adjacent plates (1)	Untreated
Pyelonephritis (1)	Treated with antibiotics and catheter for 1 wk
Adjacent segment disease (2)	1 adjacent level decompressive laminectomy; 1 treated nonoperatively

paired without incident and monitored for cerebrospinal fluid leak. There were an overall 5 (6.1%) major postoperative complications and 2 cases of adjacent level degeneration (Table 2). Only 1 patient (1%) experienced postoperative psoas weakness which resolved at 7 weeks after surgery.

At 6 months follow-up, 92.7% of patients had discontinued narcotics. At an average of 15.7 (range, 9.5–37.8) months follow-up, 68 demonstrated solid arthrodesis as confirmed on CT and dynamic radiographs. The remaining 14 (17%) patients had not completed final follow-up but are demonstrating further consolidation of fusion status without complications. Average pain and function scores at 1-year follow-up were significantly improved over preoperative scores (VAS decrease from 58.9 to 13.7, a 77% improvement, $P = 0.0006$; ODI decrease from 39.7 to 17.3, a 56% improvement, $P = 0.0017$).

Case Examples

An 83-year-old female liver-transplant recipient in sub-optimal health presented with severe bilateral neurogenic claudication despite previous lumbar decompressive laminectomies from L3–L5. Preoperative imaging revealed degenerative collapse and retrolisthesis at L2–L3 (Figure 1), the site of the most severe neurologic compression on corresponding magnetic resonance imaging (MRI). Revision posterior surgery (decompression, multilevel pedicle-screw instrumented posterolateral fusion) would have been difficult, given the scar tissue from prior surgery and potential complications relative to patient age and morbidity of the posterior procedure. A direct anterior approach would have been challenging due to aortic calcification and the level of concern.

The patient underwent a left-sided XLIF procedure with lateral plate at L2–L3, which restored spinal alignment and neuroforaminal height, indirectly decompressing the spinal nerves, obviating a posterior approach. The procedure was performed in 89 minutes with EBL up to 100 mL, and the LOS was 4 days. At 30 months after XLIF surgery (Figure 2), she is still independently ambulatory without pain and is neurologically intact.



Figure 1. Coronal CT scan of a 65-year-old woman, 2 years status post XLIF procedure, demonstrating solid fusion at L3–4.

A 43-year-old woman who had undergone T4–L2 posterior spinal fusion with a Harrington rod for AIS (adolescent idiopathic scoliosis) at age 14 years, presented with progressive symptoms of low back pain due to L2–L3 disc degeneration below her fusion. MRI and CT scan demonstrated significant disc degeneration at L2–L3 with Modic changes at L2–L3 endplates. Focal kyphosis at L2–L3 and facet arthropathy also noted (Figure 3). Dynamic radiographs demonstrated anterolisthesis of L2 on L3 of 4 to 5 mm.

The patient underwent right-sided XLIF at L2–L3 followed by same day posterior spinal fusion with instrumentation at L2–L3, local bone graft, and BMP. The procedure was performed in 221.4 minutes with EBL up to 80 mL, and the LOS was 1 day. At 3 months after XLIF surgery (Figure 4), the patient had returned to all activities including alpine skiing, surfing, biking, and golf. The patient remains pain free now more than 2 years after surgery (Figure 5).

Literature-Reported Results

A summary of the literature-reported XLIF results are shown in Table 3. Of the 14 XLIF articles available for review, 9 reported results of series with degenerative conditions (stenosis, spondylolisthesis, adjacent segment disease, *etc.*), while 5 reported results in deformity (degenerative scoliosis). The mean surgical times reported in the literature ranged from 67³⁴ to 477⁴² minutes and mean EBL from 50³⁴ to 401 mL.⁴² The average LOS was found to range between 1³⁴ and 6.2³¹ days.

Complication rates in the literature are difficult to categorize due to variations in definitions and reporting. However, broadly speaking, overall complication rates following XLIF have been generally reported in the range of 2%³⁶ to 30.4%⁴² (with an outlier of 150%,⁴¹ see Discussion); described as minor in up to 20%,³¹ and major in up to 8.6%.³³ The most common reported com-

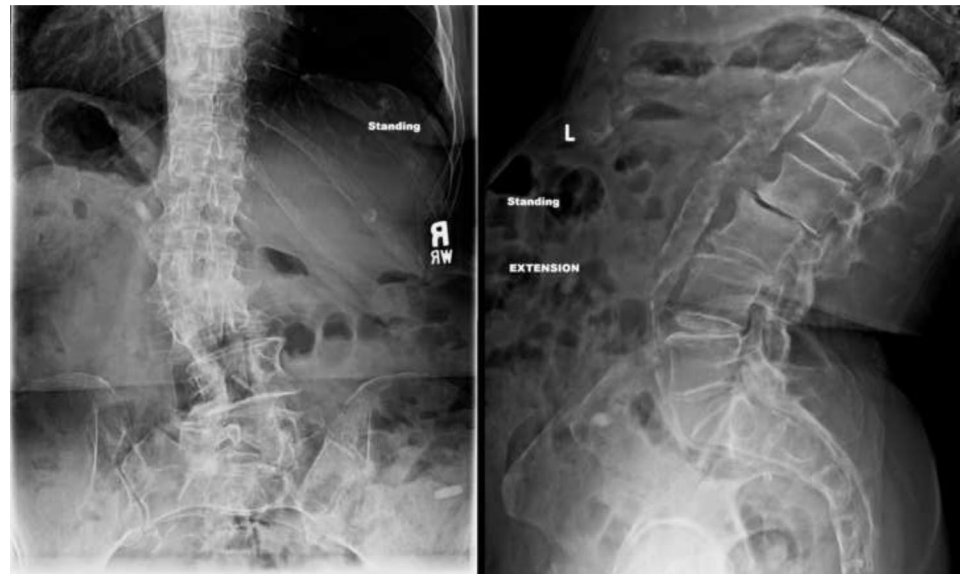


Figure 2. Preoperative AP (left) and lateral (right) radiographs of an 83-year-old woman with L2–3 degenerative collapse and claudication post-prior laminectomy at L3–5. Note aortic calcification and significant retrolisthesis at L2–3.

plaint was postoperative thigh symptoms, at a rate of 1^{36,37} to 60.1%,³⁰ described as transient, generally resolving within weeks following surgery.

Literature-reported improvements in patient-reported clinical outcome scores include ranges of 32.4%²⁹ to 80%³⁹ decrease in VAS and 39%³⁵ to 82.1%³⁰ decrease in ODI. Literature-reported fusion rates following XLIF are reported in ranges from 91%³⁵ to 100%.^{30,34,42} The results of the current retrospective cohort fall within these ranges for all measures.

Discussion

The lateral approach to the anterior column of the lumbar spine is not new, but had in fact been defined in the historical literature as an alternative to direct anterior approaches.^{44–53} There have been several anatomic descriptions of the retroperitoneum, the psoas muscle, and the lumbar plexus within it.^{54–59} There

have also been several reports that detail the surgical technique and/or case reports.^{28,60–67} The results presented herein, however, were restricted to those from published reports inclusive of safety and/or effectiveness outcomes. The 14 articles reviewed ranged in application, but were largely reports of the use of the lateral approach to interbody fusion for the treatment of multiple degenerative conditions.

Reviewing each study from a chronological perspective, and first with respect to nondeformity degenerative conditions, Rodgers *et al*³⁶ reported on the early results of 100 patients having undergone XLIF for multiple degenerative conditions in 2007. As one of the earliest reports with clinical outcomes, it described the procedure as safe and reproducible, with a low complication rate (2%), short hospital stays (average, 1.5 days), and good improvement in clinical and radiographic outcomes (reduction in VAS pain scores of 68.7%; significant correc-



Figure 3. AP (left) and lateral (right) radiographs 30 months following L2–3 XLIF with lateral plate. Patient is radiographically and clinically stable and remains asymptomatic.

Figure 4. Left picture, this 56-year-old woman had very symptomatic left anterior thigh pain and numbness due to left L3 nerve root compression. This sagittal MRI shows the cause of the compression due to degenerative collapse of the L2–L3 disc space, Modic Type II changes, and retrolisthesis. She had an uncharacterized collagen vascular disease so considerations were to keep the surgical exposure as minimal as possible. Middle picture, she underwent left sided XLIF with a PEEK spacer and a lateral titanium plate fixation and had relief of her left thigh numbness and weakness. Right picture, the lateral view shows good restoration of L2–L3 disk space height and neuroforaminal height. She was able to return to work fulltime as a medical office nurse within 1 month of the surgery.



tion of disc height, sagittal and coronal alignment out to 6 months).

In 2009, Knight *et al*³³ reported on the results of 58 lateral approach surgeries using combined techniques for multiple degenerative conditions. They reported relatively long operative times (mean, 161 minutes; range, 75–445 minutes), higher blood loss (range, 25–600 mL), and long hospital stays (average, 5 days) compared with other lateral approach reports described for similar non-deformity cases, their results raising questions about technique and learning curve (58 patients across 4 operating surgeons). The authors described a 22.4% overall

complication rate, half of which (11.2%) were described as approach-related. Six patients (10.3%) complained of psoas muscle spasm due to the approach, which was not considered a complication; postoperative hip flexion and gentle range of motion exercises were recommended. Six patients (10.3%) experienced sensory leg symptoms that the authors described as meralgia paresthetica. Two patients (3.4%) experienced a motor nerve injury, which improved over time but were residually lasting at 1 year postoperative and were considered major complications. Other major complications included myocardial infarction, subsidence (of a cylindrical cage) and loss of cor-



Figure 5. AP (left) and lateral (right) radiographs 12 months following XLIF at L2–3 followed by same day posterior spinal fusion with instrumentation. Patient remains pain free greater than 2 years postoperatively.

Table 3. Summary of Results of Published XLIF Literature

Author	Procedure	Control	Indication	Anterior Levels	Levels	Internal Fixation	No. Posterior Levels	Total n	Mean Follow-up	ORT (mins)	EBL (mL)	LOS (Days)
Deluzio <i>et al</i> ⁸²	XLIF, TLIF	PLIF	DDD	2	L1–S1	BP	2	109	45 d			1.2
Deluzio <i>et al</i> ⁸²	PLIF	XLIF	DDD	2	L1–S1	BP	2	101	45 d			3.2
Knight <i>et al</i> ⁸³	XLIF, DLIF		DDD	1–3	L2–L5			58	15 mo	161	136	5
Oliveira <i>et al</i> ⁸⁴	XLIF		DDD	1	L4–L5	None		15	2 yrs	67.3	50	1
Ozgur <i>et al</i> ⁸⁵	XLIF		DDD/Scoli	1–3	T12–L5	BP	0–5	62	2 yrs	240	183	3.9
Rodgers <i>et al</i> ⁸⁶	XLIF		DDD	1–4	L1–L5	PS		100	6 mo			
Rodgers <i>et al</i> ⁸⁷	XLIF		ASD		L			100	6 mo			1.13
Rodgers <i>et al</i> ⁸⁸	XLIF	BMI >30	DDD		L			156	3 mo			1.33
Rodgers <i>et al</i> ⁸⁸	XLIF	BMI <30	DDD		L			157	3 mo			1.27
Rodgers <i>et al</i> ⁸⁹	XLIF		DDD	1–3	L	PS	1–3	66	12 mo			
Rodgers <i>et al</i> ⁹⁰	XLIF		DDD	1–4	L	PS		600	12 mo			
Anand <i>et al</i> ²⁹	XLIF, DLIF, AxialLIF		Scoli	2–6	T12–S1	BP	2–8	12	75 d	240	164	
Anand <i>et al</i> ⁹⁰	XLIF, DLIF, AxialLIF		Scoli	1–6	T12–S1	BP	3–8	28	22.4 mo	232	241	10
Dakwar <i>et al</i> ⁸¹	XLIF		Scoli	1–6	T10–L5	LP	2–7	25	11 mo	108	53	6.2
Tormenti <i>et al</i> ⁸¹	XLIF, TLIF	PLF	Scoli	2–5	L1–L5	BP	6–12	8	10.5 mo			
Tormenti <i>et al</i> ⁸¹	PLF	XLIF, TLIF	Scoli	1–3	L2–S1	BP	4–11	4	11.5 mo			
Wang <i>et al</i> ⁸²	X,DLIF		Scoli	1–5	T12–L5	BP		23	12 mo	477	401	

Top articles related to degenerative conditions broadly labeled DDD, inclusive of stenosis, spondylolisthesis, herniated nucleus pulposus, adjacent segment degeneration, and other degenerative lumbar conditions; bottom articles related to primarily adult scoliosis.

ORT indicates operating room time; EBL, estimated blood loss; LOS, length of hospital stay; VAS, visual analog scale; ODI, Oswestry disability index; XLIF, extreme lateral interbody fusion; DLIF, direct lateral interbody fusion; AxLIF, axial lumbar interbody fusion; Scoli, degenerative scoliosis; BPS, bilateral pedicle screws; LP, anterolateral plates; PLF, posterolateral fusion; TLIF, minimally invasive transforaminal interbody fusion; DDD, degenerative disc disease; PLIF, open posterior lumbar interbody fusion; BMI, body mass index; PS, pedicle screws (uni- or bi-lateral); ASD, adjacent segment disease.

rection requiring reoperation. Although there was an average 15-month follow-up, the authors did not report clinical or radiographic results. They concluded that, overall, morbidity was lower than in traditional open procedures, and that the minimally invasive lateral approach is a valuable treatment option in this patient population.

Also in 2009, Rodgers *et al*³⁷ reported on the results of 100 patients having undergone XLIF specifically for adjacent level degeneration, that is, degenerative conditions adjacent to prior fusion surgery. The authors described the lateral approach as a good alternative to having to approach the spine through prior anterior or posterior scar tissue and revise prior instrumentation. Again recovery was reported as quick, with average 1.13 days hospital stay, low overall complication rate (9%), 1% transient thigh symptoms, and significant improvements in pain scores (67.4%) and radiographic measures, including satisfactory progression toward fusion, at least in the 6-month follow-up period.

In 2010, many more reports of outcomes following lateral approach surgery became available, with more focus on mid- to long-term results. Oliveira *et al*³⁴ reported the fusion rates of 15 stand-alone XLIF procedures using BMP. Although this study was a small patient-series, it was prospectively collected, and evaluated critically using CT studies. The authors described short operative time (67 minutes), low blood loss (average, 50 mL), minor complications (6.7%), and short hospital stay (12–48 hours). Patients experienced a statistically

significant improvement in pain and function scales at all postoperative visits. Two patients required reoperation; 1 for additional direct posterior decompression, 1 to correct heterotopic bone formation creating foraminal stenosis. Radiographically, all patients demonstrated fusion on CT scan at last follow-up. Implant subsidence occurred in 1 patient (6.7%), but did not affect clinical or fusion outcome.

Rodgers *et al*³⁸ reported on a series of more than 300 XLIF patients, categorized in about equal numbers as obese and nonobese. In this comparative analysis, the authors were able to conclude that their minimal morbidity results were not statistically affected by body habitus, and that the lateral approach is a good alternative to traditional open anterior and posterior approaches in the obese, which can be technically difficult and have been shown to result in higher incidences of infection and other complications. The same authors later reported on fusion rates following XLIF surgery.³⁹ Using CT evaluations at a minimum 12-month follow-up, 85/88 levels (96.6%) in 64/66 patients (97.0%) were fused, and the authors stated that no revisions for pseudarthrosis occurred. Clinical outcome scores were not reported, but patient satisfaction was high at 89.4%.

One of the first articles to address the application of lateral approach surgery in deformity was that by Anand *et al*,²⁹ who reported on an early experience of 12 patients having undergone combined minimally invasive procedures, inclusive of lateral interbody fusion, for the treatment of adult scoliosis. Compared with prior re-

Table 3. Continued

Complications												
Minor (%)	Major (%)	Transient Thigh Symptoms (%)	Reoperations (%)	Total Complications (%)	Cost Savings	Fusion (%)	VAS Decrease (%)	VAS Leg Decrease (%)	ODI Decrease (%)	Patient Satisfaction (%)	Elect Again (%)	Clinical Success (%)
				Significantly <PLIF	9.6%							
13.8%	8.6%	8.6%	1.7%	22.4%	\$2563							
19%	0%		13.3%	13.3%		100%	57.1%		46.9%			
		1%	1.6%			91%	37%		39%		71%	71%
		1%	2%	2%			68.7%					
			1.3%	9%			67.4%					
			1.3%	6.4%								
			1.8%	10.8%		97%	80%			89.4%	89.4%	
		25%		6.2%								
				0%			32.4%					
		60.1%		21.4%		100%	57%		82.1%			
20%	4%	12%		24%		100%	70.4%		44.2%			
		75%		150%			60.2%					
							57.9%					
		30.4%	4.3%	30.4%		100%	54.1%	63.9%				

ports, these were more complex pathologies requiring more complex procedures, but nevertheless resulted in low blood loss (average, 164 mL) compared with traditional scoliosis surgery. They reported good early pain reduction (32.4%), despite 3 of the 12 patients (25%) having what was described as dysesthesia and another with transient quadriceps weakness following surgery, both resolving within 6 weeks. This study was limited by short follow-up (average, 75 days).

The study by Ozgur *et al*³⁵ in 2010 was in a patient population with a combination of degenerative conditions, much of it adult scoliosis, with treatment including procedures up to 5 levels. In 62 patients/113 levels with 2-year follow-up, there were no major and 19% minor complications, including 3 wound events, 3 respiratory events, 2 cardiovascular events, 2 ileus, and 1 pseudarthrosis. They described transient hip flexion weakness and upper thigh numbness as a common consequence of the approach, generally resolved within 6 weeks. Pain and function improvements were maintained at 2 years and fusion was described as radiographically evident in 91% of patients.

Indeed, reported results inclusive of adult scoliosis populations have been more variable, which is not surprising, given both the multilevel nature of the pathology, as well as generally confounding demographic variables such as increased age and pre-existing age-related comorbidities. Anand *et al*³⁰ followed his 2008 report with another in 2010 on 28 patients with a mean follow-up of 22 months. They reiterated similar operative

times and blood loss to their prior report, and further defined mid- to long-term results as positive, with significant improvements in VAS pain (57%) and ODI functional outcome (82.1%) scores. They reported that all patients (100%) maintained correction of their deformity and were noted to have solid fusion on plain radiographs. They concluded that the minimally invasive approach may be particularly useful in the elderly given the demonstrated decrease in postoperative morbidity compared with traditional open procedures for deformity correction. Dakwar *et al*³¹ reported similar results in a series of 25 adult deformity patients with mean 11-month follow-up. Despite the multilevel procedural requirements, operative time was short (average, 108 minutes), blood loss minimal (average, 53 mL), with mostly minor complications (20%, 4% major). Of the patients, 12% had what was described as transient postoperative anterior thigh numbness. Clinical outcomes reported included 70.4% and 44.2% improvement in pain (VAS) and function (ODI), respectively. Of the 25 patients, 20 had minimum 6-month follow-up, and all of these (100%) were reported to have demonstrated radiographic fusion on CT scan or flexion/extension radiographs.

In the same journal issue, Wang and Mummaneni⁴² reported on 23 adult scoliosis patients who underwent lateral approach surgery with some variation to the technique described by Pimenta and others as XLIF. Procedures included interbody fusion at up to 5 levels, with bilateral posterior pedicular fixation, and the use of BMP

in the interspace. Reported operative times were long (average, 477 minutes) and blood loss was higher than generally reported (average, 401 mL). They reported no intraoperative complications, but transient thigh symptoms occurred in 7 of the 23 patients (30.4%). Pain was significantly improved at a mean follow-up of 12 months, and radiographic corrections included an average 20 degree improvement in coronal alignment, and an average 8 degree improvement in overall thoracolumbar lordosis. All interbody levels (100%) were identified as fused by CT evaluation.

Tormenti *et al*⁴¹ reported a series of 8 adult scoliosis patients having undergone a lateral-approach procedure with posterior instrumented fusion, in comparison with 4 patients having undergone posterior-approach instrumented fusion procedures (PLIF or TLIF). The study showed significant coronal curve correction capabilities using the lateral approach (70.2%, compared with 44.7% correction using a posterior-only approach); and all patients had normal lumbar lordosis after surgery. However, significant complications were reported, including bowel perforation, infection, sensory and motor disturbances, pleural effusion, hemodynamic instability, pulmonary embolism, ileus, and durotomy (during posterior instrumentation). Of the 8 patients, 6 (75%) were described as having experienced postoperative thigh paresthesias or dysesthesias. Two patients (25%) had motor neural deficits, one of which resolved after 2 months, the other persistent at last follow-up of 3 months. There were no instrumentation failures or pseudarthrosis at the last follow-up, which was an average of 11 months postoperative. Pain scores were significantly improved. Despite a high complication rate compared with other literature reports, the authors conclude that the lateral approach may provide a good alternative to traditional posterior approaches, given the low blood loss and increased correction capabilities. They go on to explain their single incident of bowel perforation as potentially a factor of a rotatory component of scoliosis deformity, as they had not encountered this problem in their nondeformity lateral approach experience. One would indeed have to consider whether the higher-than-normal complication rates in this study are reflective of the technique, experience, or particular patient cohort. As a series of only a very small number of patients ($n = 8$), it is arguably an outlier in this review, but was included to demonstrate the potential risks, and contrast those with the generally positive results reported in larger series with longer experience.

The largest series to date has been that by Rodgers *et al*,⁴⁰ who reported on the complication profile following XLIF surgery in 600 patients and 741 levels. Perioperative complications (out to 6 weeks) occurred in 6.2% of patients, and included 9 (1.5%) in-hospital surgery-related events, 17 (2.8%) in-hospital medical events, 6 (1.0%) out-of-hospital surgery-related events, and 5 (0.8%) out-of-hospital medical events. There were no wound infections, no vascular injuries, no intraoperative

visceral injuries, and 4 (0.7%) transient postoperative neurologic deficits. Eleven events (1.8%) resulted in additional procedures or reoperation.

Finally, in an editorial on the value and cost of minimally invasive procedures, Deluzio *et al*³² provide the results of a controlled cost comparison between open 2-level PLIF procedures and minimally invasive 2-level XLIF procedures, and showed a cost savings of nearly 10% or \$2500 per patient in the perioperative period, largely defined by decreased hospital stay and what are described as residual care events after surgery, such as intensive care unit usage, physical therapy, emergency room visits, *etc.*

Overall, the lateral approach to anterior column reconstruction appears to have some advantages compared with traditional anterior and posterior approaches to the lumbar spine: the XLIF approach does not require a general access surgeon, does not retract or violate the peritoneum, eliminates the need for mobilization of the great vessels and preserves the anterior and posterior longitudinal ligaments. The lateral approach is susceptible to risks similar to any spine surgery, but the incidence of these events is reportedly low and within the acceptable range of literature-reported complications following traditional spine surgical procedures.^{12,13,15,22,23,68–75} In fact, some of these risks such as postoperative medical issues and infection appear to be minimized with the use of a minimally invasive procedure compared with traditional open procedures,²⁰ presumably due to the use of smaller incisions and minimal disruption of surrounding anatomy. The most common complaint following XLIF appears to be thigh weakness and/or numbness, perhaps as a consequence of trauma to the psoas muscle during the approach. The literature suggests that this is largely transient, and recovers with soft-tissue healing following surgery, akin to paraspinal muscle weakness following posterior approach surgery. However, in a reported small percentage of patients, neurogenic motor, and/or sensory deficits may occur. The reported rates of specific neural injury are within the range of those following traditional direct anterior approaches,^{73,74} and lower than those following traditional posterior approaches.^{13,15,43–45}

Proper surgeon training is required to ensure the reduction of complications related to a lateral-approach procedure. Knowledge of the relevant anatomy and appropriate positioning of a patient is necessary for a successful procedure. The use of real-time, dynamic, and discrete neurologic monitoring during the entire procedure can lead to the protection of the lumbar plexus. Preoperative review of the axial MRI/CT images will allow the surgeon to confirm that abdominal vessels do not obstruct the lateral disc space, observe neural structures at the operative level(s), and identify that the pelvis does not obstruct access to the operative level. The use of fluoroscopic visualization during the procedure can assist a surgeon in avoiding endplate violation during disc-

ectomy and implant insertion by confirming direct lateral access to the disc space throughout.

■ Conclusion

The current cohort analysis corroborates prior reports, which together suggest that XLIF is a viable procedure option for the treatment of degenerative conditions, with minimal operative time, blood loss, and recovery, as well as demonstrated clinical, radiographic, and cost effectiveness.

Further published literature is warranted in support of XLIF in comparison to the traditional lumbar interbody fusion approaches. We anticipate reporting on final radiographic and clinical outcome data when all patients achieve longer follow-up.

■ Key Points

- The current study results corroborate and contribute to the existing literature with respect to minimal morbidity, as shown by perioperative outcomes; safety, as shown by complication rates; and effectiveness, as shown by fusion rates.
- Postoperative thigh symptoms seem to be the most common complaint, but literature suggests that they are transient and may be outweighed by the significant improvements in pain and function with the minimal morbidity advantages of the minimally invasive procedure.
- Long-term outcomes of extreme lateral interbody fusion are generally favorable, with maintained improvements in patient-reported pain and function scores as well as radiographic parameters, including high rates of fusion.

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