

Adult Degenerative Scoliosis Treated With XLIF

Clinical and Radiographical Results of a Prospective Multicenter Study With 24-Month Follow-up

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Study Design. Prospective, multicenter, single-arm study.

Objective. The objective of this study was to evaluate the clinical and radiographical results of patients undergoing extreme lateral interbody fusion (XLIF), a minimally disruptive lateral transposas retroperitoneal surgical approach for the treatment of degenerative scoliosis (DS).

Summary of Background Data. Surgery for the treatment of DS has been reported to have acceptable results but is traditionally associated with high morbidity and complication rates. A minimally disruptive lateral transposas retroperitoneal surgical approach (XLIF) has become popular for the treatment of DS. This is the first prospective, multicenter study to quantify outcomes after XLIF in this patient population.

Methods. A total of 107 patients with DS who underwent the XLIF procedure with or without supplemental posterior fixation at one or more intervertebral levels were enrolled in this study. Clinical and radiographical results were evaluated up to 24 months after surgery.

Results. Mean patient age was 68 years; 73% of patients were female. A mean of 3.0 (range, 1–6) levels were treated with XLIF per patient. Overall complication rate was low compared with traditional surgical treatment of DS. Significant improvement was seen in all clinical outcome measures at 24 months: Oswestry Disability Index,

visual analogue scale for back pain and leg pain, and 36-Item Short Form Health Survey mental and physical component summaries ($P < 0.001$). Eighty-five percent of patients were satisfied with their outcome and would undergo the procedure again. In patients with hypolordosis, lumbar lordosis was corrected from a mean of 27.7° to 33.6° at 24 months ($P < 0.001$). Overall Cobb angle was corrected from 20.9° to 15.2°, with the greatest correction observed in patients supplemented with bilateral pedicle screws.

Conclusion. This study demonstrates the use of the XLIF procedure in the treatment of DS. XLIF is associated with good clinical and radiographical outcomes, with a substantially lower complication rate than has been reported with traditional surgical procedures.

Key words: XLIF, degenerative scoliosis, Cobb, lordosis, spine, supplemental fixation, minimally disruptive, de novo scoliosis.

Level of Evidence: 3

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Adult thoracolumbar degenerative scoliosis (DS) presents as a multiplanar rotational deformity that may lead to progressive spinal deformity, chronic back pain, and neurogenic symptoms.^{1,2} Most cases of symptomatic de novo DS present in the elderly, who often have osteoporosis and experience multiple medical comorbidities. In patients with persistent symptoms refractory to nonoperative treatment, surgical intervention may be considered. Current surgical treatment techniques include posterior-only or combined anterior-posterior procedures. Reconstruction of the anterior column with interbody grafting, followed by posterior decompression with or without osteotomy and arthrodesis has been studied in patients with advanced scoliosis.^{3–5} Although effective in achieving the surgical goals, these techniques have traditionally been associated with high morbidity and risks of complications,^{3,6–8} providing impetus for the development of less invasive surgical approaches to treat DS in this vulnerable patient population.

In recent years, the extreme lateral interbody fusion (XLIF) technique, which uses a transposas retroperitoneal approach, has been popularized as a minimally disruptive alternative surgical option for anterior column reconstruction and arthrodesis.^{9–16} This approach provides the ability to release, reconstruct, and fuse the anterior column while simultaneously providing indirect decompression of neural elements

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via disc space distraction and spinal alignment^{17,18} while avoiding many of the potential complications associated with traditional anterior or posterior approaches.^{11,18–20} Lateral interbody fusion in the treatment of DS was first reported by Diaz *et al*²¹ with more than 2 years of follow-up on 39 patients. It has since been used frequently for the treatment of DS as a stand-alone treatment (without supplemental internal fixation) as well as combined with supplemental anterior or posterior instrumentation.

To date, most series reporting the results of less invasive lateral interbody fusion in the treatment of DS have been small case series of surgeons' initial experience with short-term follow-up from single institutions.^{11,22–25} This study examined the clinical and radiographical results of patients with adult DS treated by XLIF in a prospective, multicenter study with a minimum of 2 years of follow-up.

MATERIALS AND METHODS

Study Design

A prospective cohort study was conducted at 14 sites across the United States. Each participating site received institutional review board approval prior to patient enrollment.

Patient Population

Patients were eligible for study enrollment if they were at least 45 years of age, diagnosed with DS between T8 and S1 (inclusive), unresponsive to conservative treatment for at least 6 months, had a preoperative coronal Cobb angle of at least 10°, and a preoperative Oswestry Disability Index (ODI) score of at least 30/100. Patients were excluded if they had undergone previous lumbar fusion surgery or a lumbar spondylolisthesis greater than Meyerding grade II.²⁶

Study Intervention

All patients underwent an XLIF procedure, as previously described for scoliosis,²⁷ at one or more intervertebral levels. The number of levels treated, use of supplemental fixation (anterolateral or posterior), choice of bone graft material, use of direct posterior decompression, and technique for fusion of the L5–S1 level, when included, were at the discretion of the treating surgeon.

Study Measures

Clinical Measures

Clinical and radiographical values were measured preoperatively, postoperatively (up to 6 wk postsurgery), and at 3, 6, 12, and 24 months after surgery. Clinical outcome measures included ODI, visual analogue scale for back pain and leg pain (VAS back, VAS leg), 36-Item Short Form Health Survey mental component summary (SF-36 MCS), and 36-Item Short Form Health Survey physical component summary (SF-36 PCS), patient satisfaction, and neurological status.

Radiographical Measures

Neutral anterior-posterior and lateral thoracolumbar films were used to assess radiographical results. An independent

radiographical core laboratory was used to evaluate lumbar lordosis (L1–S1), coronal Cobb angle, mean disc height, and interbody bone bridging. Interbody bridging was assessed using computed tomographic scan obtained a minimum of 1 year after surgery (plain radiographs were used when computed tomographic scan was unavailable). Bridging bone was categorized as “no bridging” (no evidence of consolidation or bridging of the interbody space from endplate to endplate; continuous lucency along the bone/implant interface), “partial consolidation” (initial or continued maturation of the interbody fusion mass with new bone formation and increased density but absence of solid bridging; lack of full bony continuity across the bone/implant interface with partial lucency along the bone/implant interface and/or discontinuity in the midsubstance of the graft), or “solid bridging” (clear evidence of solid, continuous bridging bone across the involved motion segment from endplate to endplate without lucency at the bone/implant interface).

Complications

Complications were defined as any event requiring treatment or intervention or any new motor or sensory deficit. Complications were categorized by type (medical or surgical) and severity (major or minor).

Statistical Analysis

Data analysis was conducted using IBM SPSS version 19.0.0 (IBM Corp, Armonk, NY). Paired *t* test was used to compare results measured within a group, and χ^2 test was used to compare categorical data. Statistical significance was defined as $P < 0.05$.

RESULTS

Patient Demographics and Operative Data

One hundred seven patients were enrolled. Mean age was 68 years (range: 45–87 yr) and 73% (78/107) were female. Patients had a mean Charlson comorbidity index score of 1.7 (range: 0–10). Most (78%) patients presented with a history of at least 2 years of symptoms that included combined back and leg pain in 83% (86/104). In the 107 patients, 451 vertebral segments were fused. Interbody fusion was performed in 344 levels (range: 1–6 levels per patient, Figure 1), including 322 XLIF levels and 22 L5–S1 levels treated with alternative fusion techniques (in addition to XLIF at levels mentioned previously). A mean of 4.4 levels were fused per patient (range: 1–9 levels), with L3–L4 being most common, followed by L2–L3 and L4–L5. Stand-alone XLIF was performed in 18% (20/107) of patients, anterolateral fixation was used in 7% (7/107), and supplemental posterior fixation was used in 76% (80/107). Patients with supplemental posterior fixation had either unilateral (35%) or bilateral (65%) pedicle screw constructs (Figure 2). In most cases, unilateral screws were chosen over bilateral screws, because these can be applied percutaneously without having to reposition the patient from the lateral decubitus position and ultimately reduce procedure time. All unilateral pedicle screws were placed using a percutaneous

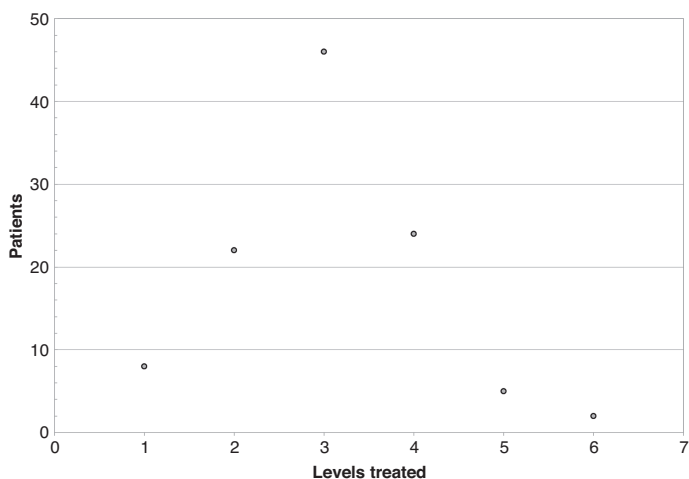


Figure 1. Number of XLIF levels treated per patient.

technique. Bilateral pedicle screws were placed using a percutaneous technique in 44% of patients and with an open technique in 56% of patients. Mean lateral operative time for the XLIF procedure was 177.9 minutes per surgery (range: 43–458 min) and 57.9 minutes per interbody fusion level. During the XLIF procedure, 62.5% of patients had a recorded estimated blood loss of 100 mL or less, and in only 9 patients (8.4%) did estimated blood loss reach 300 mL. Mean (median) length of hospital stay was 2.9 (2) days for unstaged procedures, 8.1 (8) days for staged procedures, and 3.8 (3) days overall.

Clinical Results

Eighty-two of the 107 patients (77%) were available for 24-month clinical follow-up. ODI, VAS back, VAS leg, SF-36 MCS, and SF-36 PCS scores improved significantly from pre-operative to 24-month follow-up ($P < 0.001$) (Figures 3–5). Eighty-five percent of patients were satisfied with their outcome and 86% stated that they would repeat the surgery.

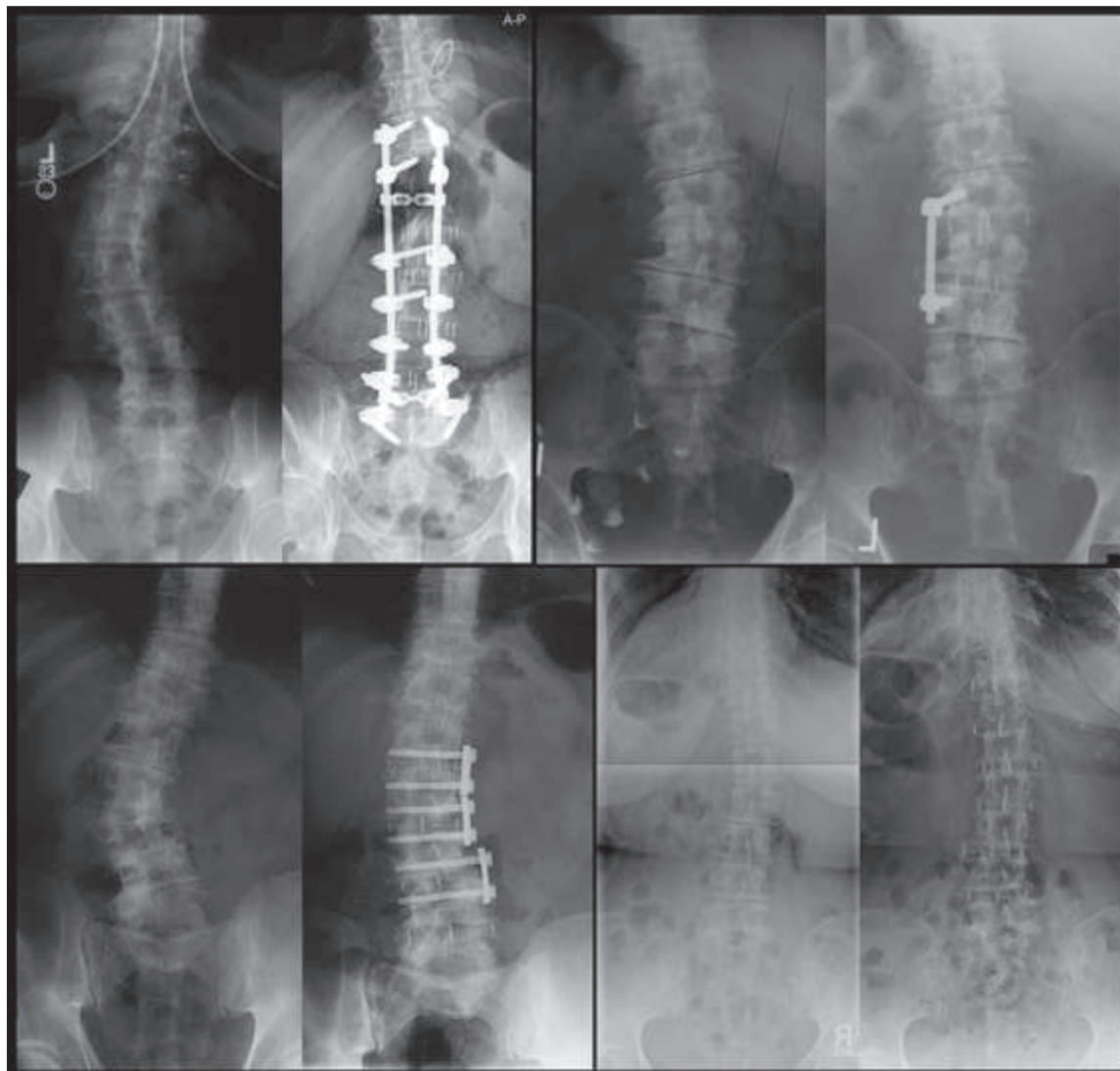


Figure 2. Pre- and postoperative examples of supplemental fixation used in this study (top left to right, bottom left to right): bilateral pedicle screws, unilateral pedicle screws, anterolateral fixation, and stand-alone treatment without supplemental fixation.

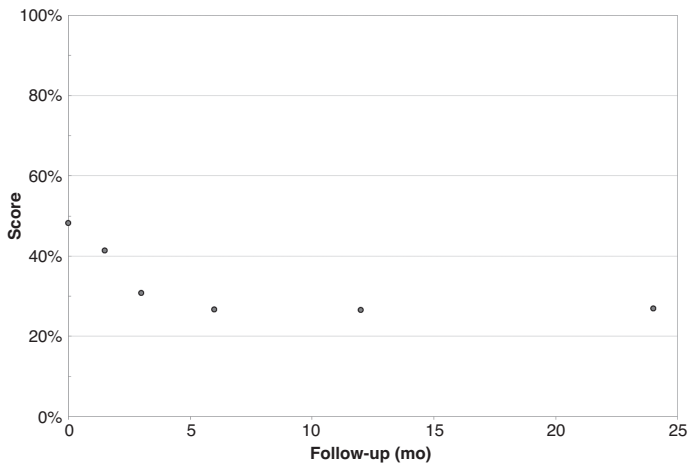


Figure 3. Mean Oswestry Disability Index scores over time. Mean improvement from preoperation (time 0) to 24 months was 21.5 SD 20.0 ($P < 0.001$).

Radiographical Results

Adequate imaging was available in 85% (91/107) of patients preoperatively, 80% (86/107) of patients postoperatively, and 76% (68/107) of patients at 24 months. The mean preoperative coronal Cobb angle for the entire cohort was 20.9°, which was corrected to an immediate postoperative mean of 13.5° (Table 1). At the 24-month visit, the mean Cobb angle was 15.2°. Supplemental bilateral pedicle screws provided the greatest initial Cobb angle correction ($P < 0.001$), with maintained correction at 24 months. Degree of Cobb angle correction did not correlate with clinical outcome (ODI, SF-36 MCS, SF-36 PCS, and VAS back or VAS leg) at 24 months ($P > 0.05$).

Preoperatively, 36 patients were hypolordotic (defined as L1–S1 lordosis $< 40^\circ$), with a mean lumbar lordosis of 27.7°. Lordosis in this population was significantly increased to an immediate postoperative mean of 37.6° ($P < 0.001$). At the 24-month visit, lordosis in this population was 33.6°. Although there was some loss of lordosis over time, the 24-month measures were significantly greater than preoperative values ($P < 0.001$). Correction of lordosis seemed to be a consequence of anterior reconstruction with XLIF; however, the limited number of patients with hypolordosis in each subgroup at baseline limited the ability to draw definitive conclusions regarding the effect of each form of supplemental fixation. In patients who were not hypolordotic at baseline, lordosis increased a mean of 3.3° after surgery ($P = 0.023$).

Mean disc height increased from 5.2 mm preoperatively to 8.7 mm immediately postoperatively and was 7.5 mm at 24-month follow-up (Table 2). Disc height was significantly increased at 24 months compared with preoperatively ($P < 0.001$).

In 10% of patients, the treated levels were unable to be assessed for fusion because of poor visualization on radiographical examinations. At the time of latest follow-up after the 12-month visit (range: 12–36 mo), 58%, 39%, and 3% of levels had solid, partial, or no consolidation, respectively. There were a total of 7 (8%) patients with at least 1 level described as a pseudarthrosis. The extent of bony consolida-

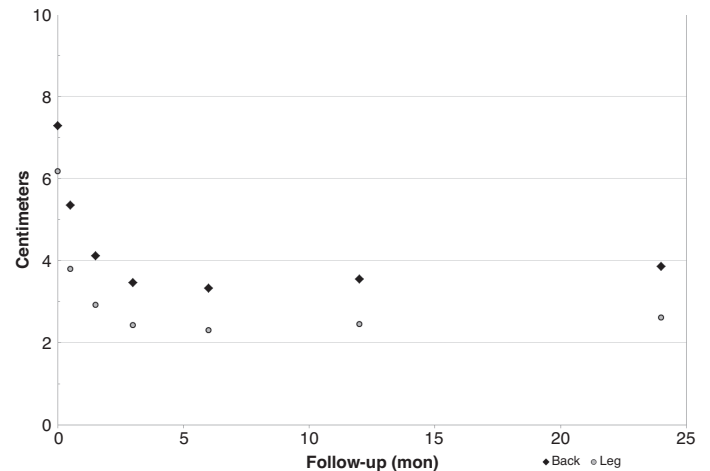


Figure 4. Mean visual analogue scale (VAS) score over time. Mean improvement from preoperation to 24 months was 3.4 SD 3.1 ($P < 0.001$) for VAS back, and 3.5 SD 3.9 ($P < 0.001$) for VAS leg.

tion was dependent on fixation method, with the greatest percentage of solid bridging bone in XLIF patients supplemented with bilateral pedicle screw instrumentation (χ^2 , $P < 0.001$).

Complications

Perioperative complications in this cohort have been previously reported in detail by Isaacs *et al*²⁰ but are also summarized here. Twenty-six of the 107 patient cohort (24.3%) (95% confidence interval: 17.2%–33.2%) had a complication: 16% minor, 12% major. The strongest predictor of complications was the total number of levels treated per patient ($P < 0.001$), and patients with minimally invasive supplemental fixation had a reduced chance of having a complication compared with open pedicle screw fixation ($P = 0.045$).

Any degree of lower extremity weakness was reported in 34% (36/107) of patients after surgery. Of those 36 patients, 29 (81%) had isolated proximal lower extremity (hip flexion) weakness thought to be related to passage of the retractors through the psoas muscle to access the spine. Leg weakness is assumed to be secondary to psoas muscle trauma during retraction, rather than neurological injury, if a patient had isolated, mild transient hip flexion weakness on the approach side. These deficits generally resolved in a time course that was consistent with muscular trauma. Twenty-eight of the 36 (78%) patients with weakness had a motor score decrease by a single grade or less, 6 (17%) patients had a decrease of 2 motor grades, and 2 patients had a decrease of greater than 2 motor grades postoperatively. Mean operative time was longer in patients with weakness than in those without ($P = 0.030$). Five (5%) patients had persistent weakness and 1 patient had a motor weakness of 4 motor grades as of the 12-month visit; the patient was lost to follow-up prior to the 24-month visit. The remaining 4 persistent motor deficits were a single motor grade.

During the course of the 2-year follow-up, 13 patients (12%) required at least 1 additional surgical procedure. Two (2%) patients underwent revisions for pseudarthrosis of an XLIF level, 4 (4%) patients underwent additional anterior

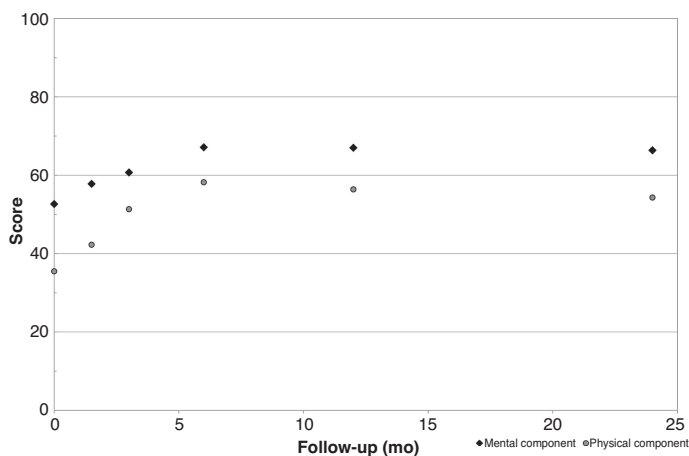


Figure 5. Mean SF-36 general health scores over time. Mean change from preoperation to 24 months was 17.9 SD 19.5 ($P < 0.001$) for physical component summary, and 13.5 SD 22.2 ($P < 0.001$) for mental component summary.

procedures at adjacent segments, and 7 (7%) patients underwent additional posterior-only procedures for reasons unrelated to nonunion (supplemental fixation addition/removal, and/or additional decompression) (Table 3).

DISCUSSION

Recent reports have demonstrated superior clinical results in patients with DS who have undergone surgical *versus* nonsurgical treatment.^{28,29} This study represents the largest prospective series analyzing the use of XLIF in the surgical treatment of DS. Significant improvements in disease-specific and quality of life outcome measures as well as radiographical parameters were observed and were maintained at 24 months. In addition, a low rate of complications was observed when compared with traditional surgical approaches.

Although the clinical results of lateral interbody fusion in the treatment of a variety of degenerative lumbar conditions have been reported,^{11,16,23,30–36} only a few small series have specifically focused on the treatment of DS. Anand *et al*²² retrospectively reviewed 28 patients with consecutive adult scoliosis who underwent minimally invasive lateral interbody fusion with percutaneous posterior instrumentation at 3 or more levels with a mean follow-up of 22 months (13–37 mo). Mean blood loss was 241 mL for the anterior surgery and 231 mL for the posterior portion. Coronal Cobb angles improved from 22° to 7° at 24-month follow-up. VAS and ODI scores improved from 7.1 and 53.5 to 3.0 and 25.9, respectively. The overall complication rate was 21%. Diaz *et al*²¹ reported on 39 patients (mean age: 68 yr) who underwent XLIF at 1 to 4 levels for the treatment of symptomatic DS. Four patients included supplemental internal fixation. Mean operative time was 125 minutes and blood loss was less than 50 mL. Mean VAS and ODI scores decreased from preoperative values of 9.1 and 49, respectively, to 4.6 and 23 at 3 years.

Complication rates with traditional procedures for the treatment of adult scoliosis have been reported as high as 66%.³⁷ In 2011, Charosky *et al*¹⁹ retrospectively reviewed 306 patients who underwent surgery for DS and reported a 39% complication rate, with nearly 20% of patients requiring reoperation. Complications ranged from cardiac and pulmonary events to surgical issues including infections, neurological injury, and hardware failure. In 2007, Daubs *et al*³⁸ studied complications in patients older than 60 years undergoing deformity surgery. They reported an overall 37% complication rate with a major complication rate of 20%, defining “major” complications as deep wound infections, pneumonia, renal failure, myocardial infarction, congestive heart failure, cerebrovascular accident, respiratory distress, pulmonary embolus, and neurological deficit. Zimmerman *et al*⁸ reported prospectively collected data on 35 patients

	Preoperation n, Mean (SD)	Postoperation n, Mean (SD)	24 mo n, Mean (SD)	Change Pre- to Postoperation Mean (SD), Percent Change, <i>P</i>	Change Postop- eration to 24 mo Mean (SD), <i>P</i>
Total population	91, 20.9 (10.4)	86, 13.5 (9.2)	68, 15.2 (10.6)	−7.4 (8.2), 35.4%, <0.001	1.6 (5.2), 0.019
Supplemental fixation					
Stand alone	14, 19.4 (5.9)	14, 15.4 (8.6)	13, 18.9 (11.4)	−5.1 (4.0), 26.2%, 0.001	3.9 (4.5), 0.025*
Lateral plate	7, 18.7 (8.0)	6, 10.3 (6.0)	4, 13.7 (9.2)	−8.5 (6.7), 45.4%, 0.027*	3.0 (5.3), 0.431*
Unilateral pedicle screws	27, 15.5 (7.0)	25, 13.2 (7.5)	21, 14.3 (8.6)	−2.3 (5.1), 14.8%, 0.035	1.1 (3.4), 0.178
Bilateral pedicle screws	43, 25.2 (12.0)	43, 13.6 (10.7)	31, 14.6 (11.7)	−11.2 (9.0), 44.4%, <0.001	1.0 (6.3), 0.385
Fixation technique†					
Percutaneous	19, 25.2 (12.5)	19, 16.9 (12.5)	16, 18.1 (13.3)	−8.4 (6.9), 33.3%, <0.001	1.8 (3.1), 0.037
Open	24, 25.2 (11.7)	24, 11.0 (8.4)	15, 10.8 (8.7)	−13.3 (9.9), 52.7%, <0.001	0.2 (8.4), 0.937

*Small patient population (<10).
 †To remove the effect of unilateral versus bilateral fixation, only patients with bilateral fixation were included in the open versus percutaneous analysis.

TABLE 2. Radiographical Results: Disc Height

	Preoperation n, Mean (SD)	Postoperation n, Mean (SD)	24 mo n, Mean (SD)	Change Pre- to Postoperation Mean (SD)	Change Postoperation to 24 mo Mean (SD), P
Total population†	266, 5.2 (2.1)	257, 8.7 (2.5)	207, 7.5 (2.5)	3.6 (3.0), <0.001	-1.2 (1.4), <0.001
Supplemental fixation					
Stand alone	43, 5.1 (2.0)	39, 7.7 (2.3)	36, 6.7 (2.1)	2.8 (3.0), <0.001	-1.2 (1.5), <0.001
Lateral plate	15, 5.4 (1.6)	12, 9.5 (2.0)	9, 7.0 (1.6)	3.7 (2.8), 0.001	-2.4 (2.2), 0.047
Unilateral pedicle screws	55, 5.2 (1.9)	57, 8.0 (2.0)	48, 7.0 (2.4)	2.9 (1.9), <0.001	-1.2 (1.4), <0.001
Bilateral pedicle screws	153, 5.3 (2.3)	146, 9.2 (2.6)	114, 8.1 (2.6)	4.1 (3.2), <0.001	-1.1 (1.3), <0.001
Fixation technique*					
Percutaneous	57, 5.0 (2.2)	62, 9.1 (2.5)	46, 8.2 (2.7)	4.3 (3.0), <0.001	-1.1 (1.3), <0.001
Open	79, 5.3 (2.2)	73, 9.5 (2.8)	58, 8.1 (2.7)	4.6 (3.3), <0.001	-1.1 (1.4), <0.001

*To remove the effect of unilateral versus bilateral fixation, only patients with bilateral fixation were included in the open versus percutaneous analysis.
†Small patient population (<10).

aged 40 years or older undergoing primary surgery for adult scoliosis with a minimum of 2-year follow-up. Patient-reported outcome data demonstrated improvement in disability and function. However, the overall complication rate was 49%. Major complications occurred in 26% of patients, including pulmonary embolism, retroperitoneal hematoma, pseudarthrosis, sacral fracture, and deep infection. Minor complications including transient brachial plexus or peroneal nerve injury, pneumothorax, atrial fibrillation, splenic laceration, dural tear, pleural effusion, and urinary tract infection occurred in 31% of patients. Pateder *et al*³⁹ reported a 2.4% 30-day mortality rate in 407 patients undergoing adult deformity surgery.

The overall complication rate of this study was 24% with 12% considered major, and there were no mortalities related to the procedure. The lower complication rate in this study is likely explained by the lateral approach to the anterior spine, avoiding many of the associated complications with traditional anterior surgery. In XLIF, the abdominal vasculature is not mobilized, the ureter is not manipulated, and the peritoneal cavity is not retracted. In Daubs' series, the anterior approach was associated with a 10.9% incidence of iliac vein tears.^{14,38} Pateder *et al*³⁹ evaluated the risk of pulmonary embolism after deformity surgery and reported a 2.4% incidence. Neither complication occurred in this series. Furthermore, less invasive approaches to the posterior spine with percutaneous fixation have consistently demonstrated a lower complication profile than their open counterparts.^{20,40-42} In particular, less invasive posterior approaches result in less blood loss and a lower incidence of postoperative wound infections.⁴³⁻⁴⁵ Moreover, early ambulation after surgery has been shown to reduce the incidence of perioperative complications.⁴⁶ As a minimally disruptive procedure with relatively short hospital stay, patients in this cohort were more likely to ambulate quickly after surgery.

Postoperative anterior thigh pain and lumbar plexus injuries have received attention as lateral transpsoas approaches have gained popularity. Pumberger *et al*⁴⁷ analyzed postoperative neurological deficits in 235 patients after lateral interbody fusion. They reported sensory deficits in 1.6%, psoas mechanical deficits in 1.6%, and lumbar plexus-related deficits in 2.9% of patients. In this study, and as reported by Isaacs *et al*,²⁰ 36 patients (33.6%) reported postoperative weakness (primarily hip flexion); however, nearly all cases were transient and only 2% had greater than 2 motor grades. The authors postulate that the transient hip flexion weakness after XLIF is a consequence of psoas muscle penetration and retraction rather than a neural injury and recommend counseling patients about this possible side effect. Moreover, the use of directional, discrete-threshold, intraoperative neural monitoring while traversing the psoas muscle is recommended. This study suggested that the duration of the XLIF procedure was a predictor of postoperative lower extremity weakness, suggesting that shorter periods of psoas muscle and lumbar plexus retraction are important to reduce these risks.

Correction of the coronal deformity is one goal of surgery in the DS patient population. A systematic review by Yadla *et al*⁷ of 49 publications reporting coronal correction in more than 2000 adult patients with DS reported the average postoperative correction of coronal deformity as 40.7% (range: 1%–87%). In 2010, Good *et al*³ reported a 43% improvement in coronal Cobb angle at 2 years in 24 patients with adult scoliosis treated with open anterior/posterior surgery. In 2009, Maeda *et al*⁴⁸ compared coronal correction of adult DS in patients treated with a circumferential approach using either bone morphogenetic protein or iliac crest bone graft; correction was 50.6% and 42.5%, respectively. The current study of XLIF in the treatment of DS found a 35% correction of the coronal Cobb angle.

TABLE 3. Summary of Revisions

Cause of Revision	Time to Revision (mo)	Initial Procedure	Revision Procedure
Pseudarthrosis	8	Stand-alone XLIF L1–L5.	L4–L5 corpectomy, L2–L5 decompression, and T11–L6 posterior fusion.
Pseudarthrosis	6	L2–L5 XLIF, L5–S1 interbody fusion, T10–S1 bilateral pedicle screw fixation.	L4–S1 ALIF, removal of all posterior fixation, L5–S1 laminectomy, bilateral pedicle screw fixation L4–S1.
Adjacent segment	5	L2–L4 XLIF, with unilateral L2 and L4 pedicle screws and rod.	L4–L5 XLIF, with unilateral pedicle screw fixation.
Adjacent segment	2	L3–L5 XLIF, with unilateral L3 and L5 pedicle screw/rod.	L2–L3 XLIF, L2–L5 laminectomy/foraminotomy, and insertion of unilateral pedicle screws.
Adjacent segment	1	L1–L5 XLIF, with bilateral fixation T10–L5.	L5–S1 ALIF removal of T10 pedicle screws.
Adjacent segment	17	Stand-alone XLIF L1–L5.	ALIF L5–S1.
Decompression, addition of supplemental fixation	19	L2–L5 XLIF, with unilateral L2 and L5 pedicle screws and rod.	L1–L5 laminectomy, hardware removal, L1–L5 decompression, addition of unilateral supplemental fixation.
Removal of supplemental fixation	20	L1–L5 XLIF, with L5–S1 interbody fusion. L1–L5 unilateral pedicle screw fixation.	L1–L3 removal of pedicle screws and rods.
Addition of supplemental fixation	1	Stand-alone XLIF L2–L5.	L3–L5 pedicle screw fixation.
Addition of supplemental fixation	1	Stand-alone XLIF L2–L5.	L2–L5 addition of bilateral posterior fixation.
Removal of supplemental fixation/decompression	5	L3–L5 XLIF, with bilateral pedicle screw fixation.	Hardware removal, L5–S1 decompression, S1 facet cyst removal.
Revision of hardware, osteotomy	3	L1–L5 XLIF, with bilateral L1–S1 pedicle screw fixation.	T3–L1 addition of supplemental fixation, revision of fixation L1–L2, osteotomy T12–L2.
Decompression, addition of supplemental fixation	9	Stand-alone XLIF L2–L5.	L5–S1 foraminotomy with supplemental posterior fixation, L1–L2 microdiscectomy.

XLIF indicates extreme lateral interbody fusion; ALIF, anterior lumbar interbody fusion.

In this study, coronal Cobb correction differed significantly on the basis of choice of supplemental fixation after XLIF, with the greatest corrections achieved in patients with open bilateral posterior pedicle fixation. These findings are likely reflective of the ability in open posterior procedures to perform posterior element releases and to better contour the rod and apply segmental compression and distraction to realign the spine. Similarly, bilateral posterior fixation afforded a greater initial increase in mean disc height after surgery with less loss of height over time.

Although coronal correction alone does not correlate with clinical outcomes,^{49,50} correction of sagittal balance has been shown to be an important predictor of quality of life.^{51,52} This study supports prior studies that have suggested that XLIF is able to correct lordosis in patients with hypolordosis,^{27,31,53} although this correction, too, may be impacted by choice of supplemental fixation.

The revision rate for pseudarthrosis in DS treated with anterior and/or posterior procedures has been reported to be between 0% and 19%.^{39,48,54–56} In this study, the rate of revision surgery for a diagnosis of pseudarthrosis was 2%. The low rate of pseudarthrosis observed after XLIF in this study is corroborated by previous studies reporting high rates of radiographical fusion.^{11,14,22,25} This low rate of pseudarthrosis after XLIF probably reflects the ability to perform a thorough discectomy and place large interbody implants sitting on the endplate apophyseal ring.

Although this prospective study is the largest published series on XLIF for the treatment of scoliosis, certain limitations are evident. Treatment alternatives were not randomized but left to surgeon preference, with resulting variability in the extent of treated levels and types of fixation. The sites chosen to participate in this study were selected on the basis of their experience with XLIF and DS. These are high-volume

clinical practices, and the results of this study are reflective of such practices. Furthermore, with a 24-month follow-up compliance of less than 85%, there is a subset of patients with unknown outcomes. Although these conditions limit the conclusions that might be drawn regarding the varied surgical constructs used, these data do reflect real-world clinical experience with the use of XLIF in the treatment of DS.

CONCLUSION

In the setting of DS, this study demonstrates that XLIF results in favorable clinical and radiographical results, while having a lower complication rate than has been reported with traditional surgical reconstruction in this patient population. Results from this study suggest that both Cobb correction and complication rate are significantly affected by choice of fixation after XLIF, with bilateral pedicle screws offering the greatest correction but a higher complication profile.

➤ Key Points

- ❑ XLIF is associated with similar clinical and radiographical results as are reported in the literature after traditional open surgical procedures, while having a substantially lower complication rate.
- ❑ Improvement of coronal and sagittal alignment is achieved with XLIF.
- ❑ Greater reduction of deformity and lower rate of subsidence were observed when XLIF was combined with bilateral pedicle screw fixation.
- ❑ Higher perioperative complications were observed when pedicle screw fixation was applied in an open fashion.

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