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Multicenter assessment of outcomes and complications associated with transforaminal versus anterior lumbar interbody fusion for fractional curve correction

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OBJECTIVE Few studies have compared fractional curve correction after long fusion between transforaminal lumbar interbody fusion (TLIF) and anterior lumbar interbody fusion (ALIF) for adult symptomatic thoracolumbar/lumbar scoliosis (ASLS). The objective of this study was to compare fractional correction, health-related quality of life (HRQL), and complications associated with L4–S1 TLIF versus those of ALIF as an operative treatment of ASLS.

METHODS The authors retrospectively analyzed a prospective multicenter adult spinal deformity database. Inclusion required a fractional curve ≥ 10°, a thoracolumbar/lumbar curve ≥ 30°, index TLIF or ALIF performed at L4–5 and/or L5–S1, and a minimum 2-year follow-up. TLIF and ALIF patients were propensity matched according to the number and type of interbody fusion at L4–S1.

RESULTS Of 135 potentially eligible consecutive patients, 106 (78.5%) achieved the minimum 2-year follow-up (mean ± SD age 60.6 ± 9.3 years, 85% women, 44.3% underwent TLIF, and 55.7% underwent ALIF). Index operations had mean ± SD 12.2 ± 3.6 posterior levels, 86.6% of patients underwent iliac fixation, 67.0% underwent TLIF/ALIF at L4–5, and 84.0% underwent TLIF/ALIF at L5–S1. Compared with TLIF patients, ALIF patients had greater cage height (10.9 ± 2.1 mm for TLIF patients vs 14.5 ± 3.0 mm for ALIF patients, p = 0.001) and lordosis (6.3° ± 1.6° for TLIF patients vs 17.0° ± 9.9° for ALIF patients, p = 0.001) and longer operative duration (6.7 ± 1.5 hours for TLIF patients vs 8.9 ± 2.5 hours for ALIF patients, p < 0.001). In all patients, final alignment improved significantly in terms of the fractional curve (20.2° ± 7.0° to 6.9° ± 5.2°), maximum coronal Cobb angle (55.0° ± 14.8° to 23.9° ± 14.3°), C7 sagittal vertical axis (5.1 ± 6.2

ABBREVIATIONS ALIF = anterior lumbar interbody fusion; ASD = adult spinal deformity; ASLS = adult symptomatic TL/L scoliosis; GCA = global coronal alignment; GCM = global coronal malalignment; HRQL = health-related quality of life; LL = lumbar lordosis; MCID = minimal clinically important difference; MCS = mental component summary; NRS = numerical rating scale; ODI = Oswestry Disability Index; PCS = physical component summary; PI = pelvic incidence; PI-LL = mismatch between PI and LL; SF-36 = 36-item Short-Form Health Survey; SRS = Scoliosis Research Society; SVA = sagittal vertical axis; TLIF = transforaminal lumbar interbody fusion; TL/L = thoracolumbar/lumbar.

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cm to 2.3 ± 5.4 cm), pelvic tilt (24.6° ± 8.1° to 22.7° ± 9.5°), and lumbar lordosis (32.3° ± 18.8° to 51.4° ± 14.1°) (all $p < 0.05$). Matched analysis demonstrated comparable fractional correction (−13.6° ± 6.7° for TLIF patients vs −13.6° ± 8.1° for ALIF patients, $p = 0.982$). In all patients, final HRQL improved significantly in terms of Oswestry Disability Index (ODI) score (42.4 ± 16.3 to 24.2 ± 19.9), physical component summary (PCS) score of the 36-item Short-Form Health Survey (32.6 ± 9.3 to 41.3 ± 11.7), and Scoliosis Research Society–22r score (2.9 ± 0.6 to 3.7 ± 0.7) (all $p < 0.05$). Matched analysis demonstrated worse ODI (30.9 ± 21.1 for TLIF patients vs 17.9 ± 17.1 for ALIF patients, $p = 0.017$) and PCS (38.3 ± 12.0 for TLIF patients vs 45.3 ± 10.1 for ALIF patients, $p = 0.020$) scores for TLIF patients at the last follow-up (despite no differences in these parameters at baseline). The rates of total complications were similar (76.6% for TLIF patients vs 71.2% for ALIF patients, $p = 0.530$), but significantly more TLIF patients had rod fracture (28.6% of TLIF patients vs 7.1% of ALIF patients, $p = 0.036$). Multiple regression analysis demonstrated that a 1-mm increase in L4–5 TLIF cage height led to a 2.2° reduction in L4 coronal tilt ($p = 0.011$), and a 1° increase in L5–S1 ALIF cage lordosis led to a 0.4° increase in L5–S1 segmental lordosis ($p = 0.045$).

CONCLUSIONS Operative treatment of ASLS with L4–S1 TLIF versus ALIF demonstrated comparable mean fractional curve correction (66.7% vs 64.8%), despite use of significantly larger, more lordotic ALIF cages. TLIF cage height had a significant impact on leveling L4 coronal tilt, whereas ALIF cage lordosis had a significant impact on restoration of lumbosacral lordosis. The advantages of TLIF may include reduced operative duration and hospitalization; however, associated HRQL was inferior and more rod fractures were detected in the TLIF patients included in this study.

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KEYWORDS adult spinal deformity; anterior lumbar interbody fusion; complications; fractional curve; outcomes; scoliosis; transforaminal lumbar interbody fusion

THE fractional curve is commonly located at the lower lumbar and lumbosacral levels below the thoracolumbar/lumbar (TL/L) curve in patients with adult degenerative or idiopathic scoliosis.[1–4] In patients with adult symptomatic TL/L scoliosis (ASLS), a concave lumbosacral fractional curve is frequently associated with neural foraminal stenosis in the cephalad-caudad orientation, which can result in nerve root compression and radiculopathy.[3–5] Moreover, the pattern of asymmetrical lumbar spine degeneration and ensuing foraminal narrowing can compress nearby dorsal root ganglia and produce more debilitating pain than compression of the myelinated axonal portions of the nerve root.[5–8] Severe radiculopathy is associated with significant disability and poor functional status, and it is a common reason for patients to pursue operative treatment of ASLS.[2,3,9,10]

Operative treatment of ASLS often involves long posterior instrumented fusion from the thoracic spine to the pelvis.[10–12] In many cases, surgeons perform transforaminal lumbar interbody fusion (TLIF) and/or anterior lumbar interbody fusion (ALIF) at the caudal lumbar and lumbosacral segments in order to achieve indirect decompression, circumferential arthrodesis, and fractional curve correction.[4,13] Although previous studies compared postoperative outcomes after TLIF versus those of ALIF, limited data are available for the subset of patients with ASLS. Moreover, current TLIF/ALIF studies often lack rigorous assessment of fractional curve correction or analysis of interbody cage measurements (i.e., cage height and lordosis). As such, our objective was to compare outcomes and complications associated with the use of L4–S1 TLIF versus those of ALIF for patients who underwent operative treatment of ASLS. The study's primary outcome was radiographic correction of a lumbosacral fractional curve, and secondary outcomes were other standard radiographic parameters of scoliosis, health-related quality-of-life (HRQL) measures, and associated complication rates.

Methods

Patient Population

This study is a retrospective analysis of a prospective multicenter database of consecutive patients with adult spinal deformity (ASD), the Prospective, Multi-Center Adult Spinal Deformity Outcomes Database Registry (PON 2020; clinical trial identifier NCT00738439).

Database enrollment was performed at multiple IRB-approved sites in North America and required patient age ≥ 18 years and ≥ 1 of the following characteristics: scoliosis ≥ 20°, C7–S1 sagittal vertical axis (SVA) ≥ 5 cm, pelvic tilt ≥ 25°, and thoracic kyphosis ≥ 60°. Patients with active infection, malignancy, or diagnosis of scoliosis other than degenerative/idiopathic scoliosis were excluded. After enrollment, the decision to pursue operative versus nonoperative treatment was determined by the operating surgeon after thoroughly discussing the risks/benefits and obtaining full informed consent from the patient, if surgery was pursued. The operative treatment plan was determined at the discretion of the operating surgeon. This included selection of interbody fusion type at L4–S1 (TLIF or ALIF) and interbody cage dimensions, such as height and/or lordosis. For study inclusion, patients had to meet all the following criteria: baseline TL/L coronal curve ≥ 30°, lumbosacral fractional curve ≥ 10°, and index operative treatment that utilized TLIF or ALIF at L4–5 and/or L5–S1 (Fig. 1). The primary focus of the present study was operative patients who achieved a minimum 2-year follow-up. Eligible operative patients who did not achieve a 2-year follow-up were also analyzed to determine if complications contributed to the lack of follow-up and potentially biased the study results.

Data Collection, Radiographic Analysis, HRQL Measures, and Complications

Preoperative and minimum 2-year postoperative follow-up data were collected, including demographic characteristics, ASD frailty index scores,[14] standard radiographic parameters, and HRQL measures. Index operative data

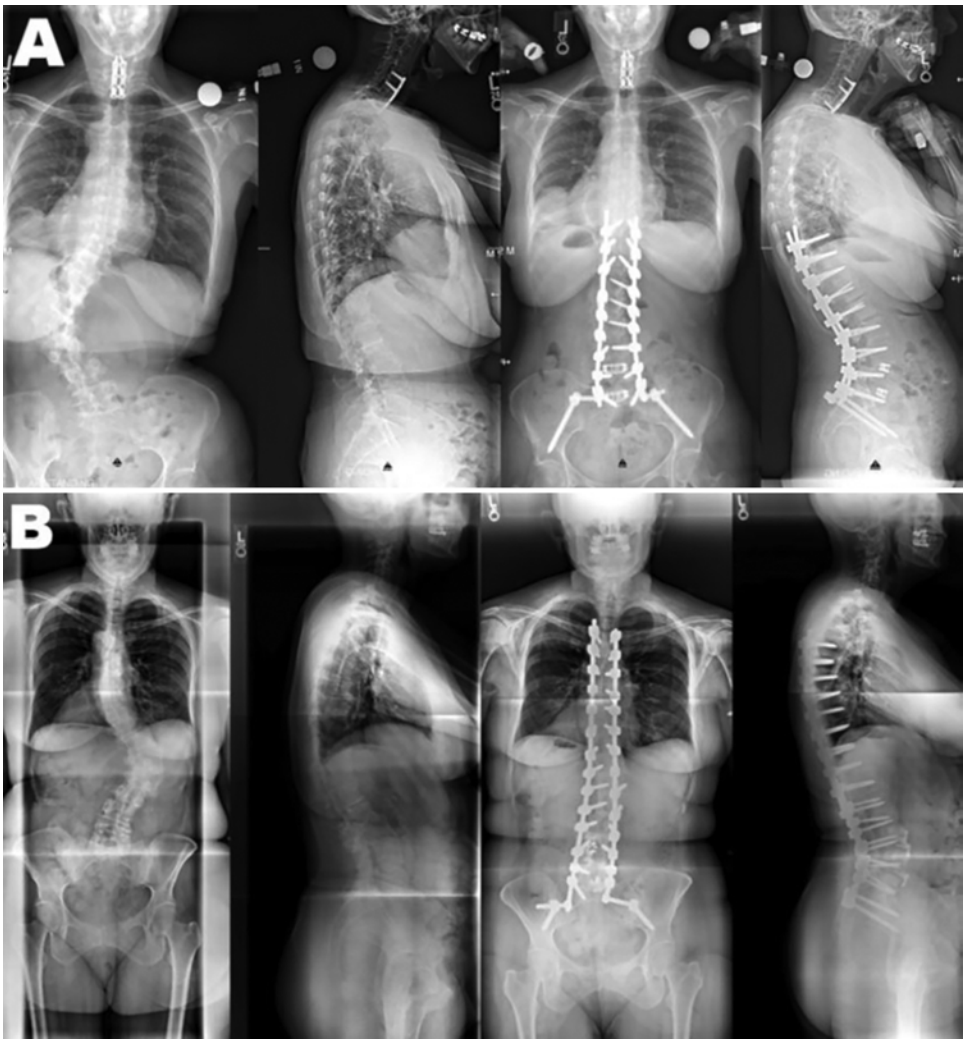

FIG. 1. Preoperative (*left*) and postoperative (*right*) standing scoliosis radiographs of 2 study patients who underwent operative treatment of adult scoliosis with long posterior instrumentation and use of distal lumbar or lumbosacral TLIF or ALIF. **A:** Index surgery with posterior instrumentation from T10 to pelvis, bilateral iliac bolt fixation, L4–5 TLIF, and L5–S1 TLIF. At both levels, the TLIF cages had a height of 12 mm and lordosis of 6°. The preoperative lumbar major curve and lumbosacral fractional curve measured 60° and 12°, respectively. The postoperative lumbar curve and fractional curve measured 10° and 2°, respectively. **B:** Index surgery with posterior instrumentation from T5 to pelvis, bilateral iliac bolt fixation, and L3–S1 ALIF. The L4–5 ALIF cage had a height of 16 mm and lordosis of 8°. The L5–S1 ALIF cage had a height of 14 mm and lordosis of 8°. The preoperative thoracolumbar major curve and lumbosacral fractional curve measured 64° and 22°, respectively. The postoperative thoracolumbar curve and fractional curve measured 22° and 2°, respectively.

included interbody cage height and lordosis, if available. Radiographic analysis utilized full-length, free-standing anteroposterior and lateral spine radiographs (36-inch-long cassette films). All radiographic measurements were performed at a central location by using validated software (SpineView, ENSAM Laboratory of Biomechanics)[15,16] and standard techniques.[17] The assessed radiographic measurements included global coronal alignment (GCA) (horizontal offset from midsacrum to C7 plumb line), pelvic obliquity, coronal Cobb angles (thoracolumbar, lumbar, lumbosacral), coronal tilt of the L4 and L5 superior endplates, C7 SVA, pelvic tilt, lumbar lordosis (LL) (at T12–S1), mismatch between pelvic incidence (PI) and LL (PI-LL), segmental LL (at L4–5, L5–S1, and L4–S1), and thoracic kyphosis (at T4–T12). To evaluate GCA and global coronal malalignment (GCM), patients were also analyzed in terms of Qiu type (type A, GCA < 3 cm; type B, GCM > 3 cm toward major concavity; type C, GCM ≥ 3 cm toward major convexity).[18] Plain radiographs were reviewed to assess anterior/posterior fusion status and were rated as bilateral solid fusion (grade A), unilateral solid fusion (grade B), partial fusion (grade C), or no fusion (grade D). TLIF and ALIF patients without fusion (grade D) were compared at the 2-year follow-up.[19]

Standardized assessment of HRQL included scores on the Oswestry Disability Index (ODI),[20] physical component summary (PCS) and mental component summary (MCS) of the 36-item Short-Form Health Survey (SF-36),[21] and the Scoliosis Research Society (SRS)–22r questionnaire

TABLE 1. Unmatched and matched comparisons of baseline data of patients who underwent L4–S1 TLIF versus ALIF

Parameter	Unmatched Analysis				Matched Analysis		
	All (n = 106)	TLIF (n = 47)	ALIF (n = 59)	p Value*	TLIF (n = 28)	ALIF (n = 28)	p Value*
Age at index surgery, yrs	60.6 ± 9.3	61.3 ± 8.3	60.0 ± 10.0	0.450	61.1 ± 8.7	62.6 ± 8.0	0.515
Female sex	91 (85.8)	38 (80.9)	53 (89.8)	0.188	22 (78.6)	25 (89.3)	0.469
BMI, kg/m^2	26.7 ± 4.7	27.4 ± 5.3	26.2 ± 4.1	0.228	28.1 ± 6.0	26.2 ± 3.8	0.174
Prior spine surgery	30 (28.3)	15 (31.9)	15 (25.4)	0.461	8 (28.6)	10 (35.7)	0.567
ASA physical status classification	2.2 ± 0.5	2.2 ± 0.5	2.2 ± 0.6	0.856	2.2 ± 0.6	2.3 ± 0.6	0.492
CCI	1.5 ± 1.7	1.6 ± 1.5	1.4 ± 1.8	0.365	1.8 ± 1.5	1.7 ± 2.1	0.468
Osteoporosis	19 (17.9)	9 (19.1)	10 (16.9)	0.769	6 (21.4)	7 (25.0)	0.752
ASD frailty index	3.1 ± 1.5	3.5 ± 1.4	2.9 ± 1.5	**0.031**	3.5 ± 1.4	3.1 ± 1.6	0.273

ASA = American Society of Anesthesiologists; CCI = Charlson Comorbidity Index.
Values are shown as mean ± SD or number (percent) unless indicated otherwise. Boldface type indicates statistical significance ($p < 0.05$).
* Determined with the Mann-Whitney U-test, independent-samples t-test, chi-square test, or Fisher exact test, as appropriate.

and its 5 subdomains (activity, pain, appearance, mental health, and satisfaction).[22,23] Back and leg pain were assessed by using the numerical rating scale (NRS), with severity score ranging from 0 (no pain) to 10 (unbearable pain). Values for the minimal clinically important difference (MCID) have been established to provide clinical context when assessing HRQL.[24–26] In this study, the last postoperative HRQL outcome measures were analyzed to determine the percentage of patients who achieved ≥ 1 MCID threshold of improvement.[24–26]

Assessment of complications was based on findings on physical examination and imaging review, as well as information included on standardized collection forms. Study coordinators at each site assisted with collection of complications during postoperative follow-up. Regular data audits were performed at a central center to help ensure accuracy and completeness of data collection. Complications were classified as major or minor according to the criteria of Smith et al.[27,28]

Statistical Analysis

Data are presented as mean ± SD for continuous variables and as number (percent) for categorical variables. The Shapiro-Wilk test was used to assess normality of data, and parametric or nonparametric tests were performed as appropriate. Univariate analysis utilized the independent-samples t-test, paired t-test, Mann-Whitney U-test, Wilcoxon signed-rank test, chi-square test, and Fisher exact test. Multiple regression analysis was performed to assess potential associations between interbody cage measurements and segmental alignment. Patients who underwent index operative treatment with TLIF at L4–5 and/or L5–S1 (TLIF cohort) were matched to those who underwent ALIF at L4–5 and/or L5–S1 (ALIF cohort). Matching was performed at a 1:1 ratio with a caliper of 0.25 standard deviations by using propensity scores derived from index surgical covariates (number of interbody fusions above L4, TLIF/ALIF at L4–5, TLIF/ALIF at L5–S1). All tests were 2-tailed, and p values < 0.05 were considered statistically significant. Because these analyses were exploratory, no corrections for multiple comparisons were performed. Statistical analysis was performed by using IBM SPSS Statistics for Windows version 26.0 (IBM Corp.) and Stata version 16.0 (StataCorp).

Results

Patient Population

At the time of data extraction (September 21, 2020), we identified 135 consecutively treated patients who met the study inclusion criteria and were potentially eligible for 2-year follow-up. Of these, 106 (78.5%) patients achieved the minimum 2-year follow-up and were included in the primary analysis (Supplemental Fig. 1). Prior to matching, the TLIF and ALIF cohorts comprised 47 (44.3%) and 59 (55.7%) patients, respectively. Table 1 summarizes the baseline data, including demographic characteristics, history of spine surgery, and most commonly reported comorbidities. Most parameters in Table 1 were comparable, except TLIF patients (3.5 ± 1.4 [frail]) had greater ASD frailty index scores than ALIF patients (2.9 ± 1.5 [not frail]) ($p = 0.031$).[14] After 1:1 matching, the TLIF and ALIF cohorts each comprised 28 patients, and there were no statistically significant differences between cohorts (Table 1).

Index Operative Data

Index operative data are summarized in Table 2. Prior to matching, ALIF was associated with significantly longer operative duration (6.2 ± 1.5 hours for TLIF patients vs 9.2 ± 3.2 hours for ALIF patients, $p < 0.001$) and length of hospitalization (7.9 ± 4.1 days for TLIF patients vs 11.5 ± 9.0 days for ALIF patients, $p = 0.020$). After matching, ALIF was still associated with significantly longer operative duration (6.7 ± 1.5 for TLIF patients vs 8.9 ± 2.5 hours for ALIF patients, $p < 0.001$) but not length of hospitalization. Both unmatched and matched analysis demonstrated that ALIF was associated with significantly greater interbody cage height (10.9 ± 2.1 mm for TLIF patients vs 14.5 ± 3.0 mm for ALIF patients, $p = 0.001$) and lordosis (6.3° ± 1.6° for TLIF patients vs 17.0° ± 9.9° for ALIF patients, $p = 0.001$) at L5–S1.

Radiographic Assessment

Table 3 presents coronal and sagittal radiographic

TABLE 2. Unmatched and matched comparisons of index operative data of patients who underwent L4–S1 TLIF versus ALIF

Parameter	Unmatched Analysis				Matched Analysis		
	All (n = 106)	TLIF (n = 47)	ALIF (n = 59)	p Value*	TLIF (n = 28)	ALIF (n = 28)	p Value*
IBF							
L4–5	71 (67.0)	26 (55.3)	45 (76.3)	**0.023**	17 (60.7)	14 (50.0)	0.420
w/ L4 SPO	39 (36.8)	18 (38.3)	21 (35.6)	0.774	14 (50.0)	10 (35.7)	0.280
L5–S1	89 (84.0)	37 (78.7)	52 (88.1)	0.190	27 (96.4)	26 (92.9)	>0.99
w/ L5 SPO	34 (32.1)	20 (42.6)	14 (23.7)	**0.039**	16 (57.1)	10 (35.7)	0.108
Above L4†	1.0 (1.4)	0.4 (0.9)	1.5 (1.5)	**<0.001**	0.6 (1.1)	0.5 (1.1)	0.606
Total‡	2.6 (1.7)	1.9 (1.2)	3.3 (1.8)	**<0.001**	2.4 (1.3)	2.1 (1.3)	0.303
L4–5 cage							
Height, mm§	11.4 ± 2.1	11.0 ± 1.8	11.7 ± 2.3	0.301	11.7 ± 1.6	12.7 ± 2.3	0.268
Lordosis, °¶	6.0 ± 2.8	6.2 ± 2.6	5.8 ± 3.0	0.375	7.1 ± 2.1	6.3 ± 3.8	0.625
L5–S1 cage**							
Height, mm	12.5 ± 2.6	11.1 ± 2.0	13.5 ± 2.6	**0.001**	10.9 ± 2.1	14.5 ± 3.0	**0.001**
Lordosis, °	9.2 ± 6.5	6.6 ± 1.9	11.0 (7.9)	**0.031**	6.3 ± 1.6	17.0 ± 9.9	**0.001**
Anterior-posterior approach	62 (58.5)	3 (6.4)	59 (100.0)	**<0.001**	3 (10.7)	28 (100.0)	**<0.001**
Staged readmission	13 (12.3)	0 (0)	13 (22.0)	**0.001**	0 (0)	9 (32.1)	**0.002**
Posterior levels fused	12.2 ± 3.6	12.5 ± 3.3	12.1 ± 3.8	0.621	12.0 ± 3.0	12.4 ± 3.2	0.980
UIV location							
T2–5	43 (40.6)	20 (42.6)	23 (39.0)	0.628	9 (32.1)	12 (42.9)	0.332
T6–8	5 (4.7)	1 (2.1)	4 (6.8)		0 (0)	1 (3.6)	
T9–12	54 (50.9)	25 (53.2)	29 (49.2)		19 (67.9)	14 (50.0)	
L1–3	4 (3.8)	1 (2.1)	3 (5.1)		0 (0)	1 (3.6)	
Iliac fixation	92 (86.8)	42 (89.4)	50 (84.7)	0.486	26 (92.9)	24 (85.7)	0.669
Decompression	74 (69.8)	29 (61.7)	45 (76.3)	0.105	18 (64.3)	23 (82.1)	0.131
SPO procedures per patient	4.1 ± 3.2	3.7 ± 3.3	4.4 ± 3.0	0.168	3.6 ± 3.1	5.2 ± 2.8	0.066
3CO††	8 (7.5)	5 (10.6)	3 (5.1)	0.462	2 (7.1)	2 (7.1)	>0.99
Op duration, hrs‡‡	7.8 ± 3.0	6.2 ± 1.5	9.2 ± 3.2	**<0.001**	6.7 ± 1.5	8.9 ± 2.5	**<0.001**
EBL, L‡‡	1.9 ± 1.6	2.1 ± 1.9	1.7 ± 1.4	0.230	2.3 ± 2.2	1.9 ± 1.5	0.430
LOS, days‡‡	9.9 ± 7.4	7.9 ± 4.1	11.5 ± 9.0	**0.020**	7.9 ± 4.2	13.0 ± 11.7	0.098

3CO = 3-column osteotomy; EBL = estimated blood loss; IBF = interbody fusion; LOS = length of index hospital stay; SPO = Smith-Petersen osteotomy; UIV = upper instrumented vertebral level.

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

* Determined with the Mann-Whitney U-test, independent-samples t-test, chi-square test, or Fisher exact test, as appropriate.

† The majority of IBF procedures performed above L4 were TLIF/ALIF.

‡ IBF was recorded as T10–S1 in the database.

§ Data were available for 50 patients (unmatched) and 21 patients (matched).

¶ Data were available for 51 patients (unmatched) and 21 patients (matched).

** Data were available for 57 patients (unmatched) and 34 patients (matched).

†† Includes pedicle subtraction osteotomy and vertebral column resection.

‡‡ Includes all stages of index procedure.

measurements at baseline and last follow-up (mean ± SD radiographic follow-up duration 3.2 ± 1.2 years). For all study patients, most assessed radiographic parameters had significantly improved at the last follow-up, including the maximum coronal Cobb angle (55.0° ± 14.8° to 23.9° ± 14.3°), fractional curve (20.2° ± 7.0° to 6.9° ± 5.2°), C7–S1 SVA (5.1 ± 6.2 cm to 2.3 ± 5.4 cm), and PI-LL (15.9° ± 15.7° to 1.7° ± 14.5°) (all $p < 0.05$). Both unmatched and matched analysis demonstrated no statistically significant differences between baseline and final radiographic measures (Table 3). Matched analysis demonstrated that lumbosacral fractional curve correction was comparable between TLIF (–13.6° ± 6.7° [66.7% correction]) and ALIF (–13.6° ± 8.1° [64.8% correction]) patients ($p = 0.982$). Of note, the durations of radiographic follow-up for the matched cohorts were comparable.

Unmatched and matched radiographic analysis demonstrated no differences in the rates of nonfusion (grade D) between TLIF and ALIF patients at the 2-year follow-up (Supplemental Table 1).[19]

Matched subanalysis of baseline Qiu type showed that 27 (48.2%) patients had Qiu type A (GCA < 3 cm), 6 (10.7%) patients had Qiu type B (concave GCM > 3 cm), and 23 (41.1%) patients had Qiu type C (convex GCM > 3

TABLE 3. Unmatched and matched comparisons of radiographic data of patients who underwent L4–S1 TLIF versus ALIF

Parameters	Unmatched Analysis				Matched Analysis		
	All (n = 106)	TLIF (n = 47)	ALIF (n = 59)	p Value*	TLIF (n = 28)	ALIF (n = 28)	p Value*
Coronal†							
GCA, cm							
Baseline	3.3 ± 2.7	2.7 ± 2.1	3.8 ± 3.0	0.083	3.0 ± 2.0	3.6 ± 2.9	0.806
Last follow-up	2.6 ± 2.2	3.0 ± 2.4	2.3 ± 2.0	0.146	3.0 ± 2.5	2.6 ± 2.1	0.646
p value‡	0.084	0.320	**0.003**		0.820	0.111	
Pelvic obliquity, °							
Baseline	2.7 ± 1.9	2.9 ± 1.9	2.5 ± 1.8	0.320	2.8 ± 2.1	2.4 ± 1.7	0.670
Last follow-up	2.3 ± 1.9	2.5 ± 2.0	2.1 ± 1.8	0.177	2.3 ± 1.9	1.4 ± 1.3	0.116
p value‡	**0.003**	0.086	**0.014**		0.165	**0.001**	
Cobb angle							
Maximum, °							
Baseline	55.0 ± 14.8	54.9 ± 17.9	55.1 ± 11.8	0.591	52.8 ± 19.0	53.9 ± 12.5	0.394
Last follow-up	23.9 ± 14.3	24.2 ± 15.4	23.7 ± 13.4	0.934	20.5 ± 14.6	24.2 ± 15.1	0.330
p value‡	**<0.001**	**<0.001**	**<0.001**		**<0.001**	**<0.001**	
Thoracolumbar, °							
Baseline	51.4 ± 20.0	50.3 ± 25.7	52.2 ± 14.6	0.743	50.1 ± 25.8	50.8 ± 17.2	0.924
Last follow-up	23.0 ± 14.5	23.0 ± 17.7	23.0 ± 11.8	0.690	20.9 ± 17.5	20.7 ± 11.3	0.748
p value‡	**<0.001**	**<0.001**	**<0.001**		**<0.001**	**<0.001**	
Lumbar, °							
Baseline	50.8 ± 14.3	49.0 ± 14.2	52.5 ± 14.4	0.370	45.7 ± 11.6	49.3 ± 14.4	0.440
Last follow-up	21.4 ± 14.4	20.2 ± 12.9	22.5 ± 15.9	0.901	14.7 ± 8.4	26.3 ± 18.2	0.165
p value‡	**<0.001**	**<0.001**	**<0.001**		**<0.001**	**<0.001**	
Lumbosacral fractional, °							
Baseline	20.2 ± 7.0	19.4 ± 7.2	20.8 ± 6.9	0.231	20.4 ± 7.6	21.0 ± 6.6	0.611
Last follow-up	6.9 ± 5.2	7.1 ± 5.4	6.8 ± 5.1	0.834	6.8 ± 5.4	7.4 ± 5.4	0.755
p value‡	**<0.001**	**<0.001**	**<0.001**		**<0.001**	**<0.001**	
Sagittal							
C7–S1 SVA, cm							
Baseline	5.1 ± 6.2	4.9 ± 6.5	5.2 ± 6.0	0.802	4.9 ± 6.6	6.9 ± 6.4	0.267
Last follow-up	2.3 ± 5.4	2.4 ± 5.2	2.2 ± 5.6	0.772	2.8 ± 5.7	3.0 ± 5.7	0.917
p value‡	**<0.001**	**0.008**	**0.002**		0.071	**0.011**	
Pelvic tilt, °							
Baseline	24.6 ± 8.1	25.5 ± 8.5	23.8 ± 7.7	0.292	25.8 ± 7.9	24.7 ± 7.7	0.601
Last follow-up	22.7 ± 9.5	23.0 ± 9.3	22.5 ± 9.8	0.813	23.8 ± 9.3	23.9 ± 8.2	0.962
p value‡	**0.021**	0.052	0.195		0.222	0.598	
PI-LL, °							
Baseline	15.9 ± 15.7	15.6 ± 15.4	16.2 ± 16.1	0.807	16.4 ± 17.2	18.5 ± 15.2	0.641
Last follow-up	1.7 ± 14.5	0.5 ± 13.3	2.7 ± 15.4	0.710	–0.1 ± 13.3	4.6 ± 11.6	0.164
p value‡	**<0.001**	**<0.001**	**<0.001**		**<0.001**	**<0.001**	
LL at T12–S1, °							
Baseline	32.3 ± 18.8	30.1 ± 17.9	34.1 ± 19.5	0.285	29.2 ± 17.2	34.6 ± 19.2	0.276
Last follow-up	51.4 ± 14.1	51.0 ± 13.2	51.7 ± 14.9	0.780	50.8 ± 11.8	52.4 ± 13.0	0.635
p value‡	**<0.001**	**<0.001**	**<0.001**		**<0.001**	**<0.001**	
Thoracic kyphosis at T4–12, °							
Baseline	–30.7 ± 16.9	–31.9 ± 17.3	–29.8 ± 16.6	0.531	–31.7 ± 17.8	–32.7 ± 19.5	0.848
Last follow-up	–49.1 ± 15.9	–49.9 ± 14.9	–48.5 ± 16.7	0.673	–53.4 ± 14.5	–50.9 ± 19.1	0.584
p value‡	**<0.001**	**<0.001**	**<0.001**		**<0.001**	**<0.001**	

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TABLE 3. Unmatched and matched comparisons of radiographic data of patients who underwent L4–S1 TLIF versus ALIF

Values are shown as mean ± SD unless indicated otherwise. Boldface type indicates statistical significance ($p < 0.05$).
* Determined with Mann-Whitney U-test or independent-samples t-test.
† Absolute values were measured.
‡ Values determined at baseline were compared with those determined at last follow-up by using the Wilcoxon signed-rank test or paired t-test.

cm).[18] Analysis of baseline Qiu type demonstrated no statistically significant difference between TLIF and ALIF patients ($p = 0.407$). At the last follow-up, 31 (55.4%) patients had Qiu type A with GCA < 3 cm and 25 (44.6%) patients had postoperative GCM > 3 cm. The rates of postoperative GCM for TLIF (53.6%) and ALIF (35.7%) patients were comparable at the last-follow-up ($p = 0.179$).

Clinical Outcomes

Clinical outcomes according to the HRQL measures at baseline and last follow-up (mean ± SD clinical follow-up duration 3.2 ± 1.3 years) are presented in Table 4. For all patients, assessed HRQL and NRS pain scores at the last follow-up had significantly improved from those at baseline. Matched analysis demonstrated worse ODI (30.9 ± 21.1 for TLIF patients vs 17.9 ± 17.1 for ALIF patients, $p = 0.017$) and PCS (38.3 ± 12.0 for TLIF patients vs 45.3 ± 10.1 for ALIF patients, $p = 0.020$) scores for patients who underwent TLIF at the last follow-up (despite no difference in these matched parameters at baseline). Of note, the durations of clinical follow-up of the matched cohorts were comparable.

Complications

At the last follow-up, 78 of 106 (73.6%) patients had ≥ 1 complication, for a total of 155 reported complications (27 patients underwent reoperation, 56 had major complications, and 72 had minor complications). The percentages of patients with any complication were comparable (36 [76.6%] TLIF patients vs 42 [71.2%] ALIF patients, $p = 0.530$). Also, the percentages of patients with complications resulting in reoperation were comparable (10 [21.3%] TLIF patients vs 12 [20.3%] ALIF patients, $p = 0.906$).

For TLIF patients, the most commonly reported complication was rod fracture (3 patients underwent reoperation and 10 had major complications), and the most common indication for reoperation was also rod fracture (n = 3). For ALIF patients, the most commonly reported complication was durotomy (8 patients had minor complications) and proximal junctional kyphosis (1 patient underwent reoperation, and 7 had minor complications), and the most common indication for reoperation was rod fracture (n = 4). Other reported complications for ALIF included ileus (4 patients had minor complications), visceral injury (2 had major complications), and vascular injury (1 had major complications). Supplemental Table 2 summarizes all reported complications by category type and severity.

Supplemental Tables 3 and 4 present the percentages of unmatched and matched patients with reported complications according to type and severity. Supplemental Tables 5 and 6 report the results of unmatched and matched analysis, which demonstrated a significantly greater percentage of TLIF patients with surgical implant failure due to rod fracture (28.6% of TLIF patients vs 7.1% of ALIF patients, $p = 0.036$). Table 5 summarizes data of 16 study patients with reported rod fracture. Rod fracture location was confirmed below L3 pedicle screws in 11 of 16 (68.8%) patients. Illustrative radiographs for these patients depict rod fractures and revisions with accessory supplemental rods (Fig. 2). No rod fractures were reported after revision with accessory rod constructs.

Of 135 potentially eligible operative patients at the time of data extraction, 29 (21.5%) patients (19 TLIF and 10 ALIF patients) did not achieve the minimum 2-year radiographic follow-up. Of these 29 patients, 20 (69.0%) had ≥ 1 complication, for a total of 32 reported complications (11 patients underwent reoperation, 9 had major complications, and 12 had minor complications). The most commonly reported complication was proximal junctional kyphosis (n = 5), and the most common operative complications were rod fracture (n = 2) and radiculopathy (n = 2).

Segmental Alignment and TLIF/ALIF Cage Dimensions

Supplemental Table 7 summarizes postoperative changes in L4–5 and L5–S1 segmental alignment with use of TLIF or ALIF at the corresponding level. There were no statistically significant differences between TLIF patients and ALIF patients in terms of L4 coronal tilt, L5 coronal tilt, L4–5 segmental lordosis, L5–S1 segmental lordosis, and L4–S1 segmental lordosis.

Table 6 summarizes the results of multiple regression analysis of postoperative changes in segmental alignment as a function of TLIF/ALIF cage height and lordosis. Notable results included the following: 1) 1-mm increase in L4–5 TLIF cage height led to a significant reduction in L4 coronal tilt by 2.2° ($p = 0.011$); and 2) 1° increase in L5–S1 ALIF cage lordosis led to a significant increase in L5–S1 segmental lordosis by 0.4° ($p = 0.045$). Of note, no cages included in the present study were expandable. Cage material data are available in Supplemental Results.

Discussion

Patients with ASLS often present with a lumbosacral fractional curve located just below their major curve.[1–4] Neural foraminal stenosis is commonly located ipsilateral to the fractional concavity, and this can compress nerve roots and cause severe radiculopathy and pain-related functional disability.[5–8] These symptoms may be a significant factor associated with the decision to pursue operative treatment.[9,10] As a surgical corollary, inadequate correction of the fractional curve may lead to persistent pain and poor outcomes.[2–4] Moreover, recent evidence suggests that inadequate correction of the fractional curve may be a significant risk factor associated with postoperative

TABLE 4. Unmatched and matched comparisons of HRQL data at baseline and last follow-up of patients who underwent L4–S1 TLIF versus ALIF

Parameter	Unmatched Analysis				Matched Analysis		
	All (n = 105)	TLIF (n = 47)	ALIF (n = 58)	p Value*	TLIF (n = 27)	ALIF (n = 28)	p Value*
ODI†							
Baseline	42.4 ± 16.3	46.1 ± 15.0	39.5 ± 16.8	**0.039**	46.9 ± 16.0	42.3 ± 16.0	0.294
Last follow-up‡	24.2 ± 19.9	29.2 ± 20.1	20.2 ± 18.9	**0.015**	30.9 ± 21.1	17.9 ± 17.1	**0.017**§
p value¶	**<0.001**§	**<0.001**§	**<0.001**§		**0.001**§	**<0.001**§	
SF-36**							
PCS							
Baseline	32.6 ± 9.3	30.5 ± 8.5	34.2 ± 9.6	**0.044**	29.8 ± 8.5	32.2 ± 8.2	0.311
Last follow-up‡	41.3 ± 11.7	38.4 ± 11.3	43.7 ± 11.7	**0.022**‡	38.3 ± 12.0	45.3 ± 10.1	**0.020**§
p value¶	**<0.001**§	**<0.001**§	**<0.001**§		**0.004**§	**<0.001**§	
MCS							
Baseline	47.2 ± 12.6	45.0 ± 13.6	48.9 ± 11.6	0.164	47.3 ± 14.1	46.3 ± 13.4	0.798
Last follow-up‡	50.9 ± 11.1	50.1 ± 11.6	51.5 ± 10.8	0.558	52.2 ± 10.2	53.3 ± 8.3	0.801
p value¶	**0.003**	**0.008**	0.099		0.067	**0.009**	
SRS-22r††							
Activity							
Baseline	3.0 ± 0.8	2.8 ± 0.8	3.1 ± 0.8	0.144	2.9 ± 0.8	3.0 ± 0.8	0.659
Last follow-up‡	3.6 ± 0.9	3.6 ± 1.0	3.6 ± 0.8	0.709	3.6 ± 1.0	3.6 ± 0.8	0.988
p value¶	**<0.001**§	**<0.001**§	**<0.001**§		**0.004**§	**0.011**§	
Pain							
Baseline	2.5 ± 0.9	2.3 ± 0.9	2.7 ± 0.8	**0.013**	2.1 ± 0.7	2.6 ± 0.7	**0.038**
Last follow-up‡	3.6 ± 1.0	3.4 ± 1.0	3.6 ± 1.0	0.353	3.5 ± 1.0	3.8 ± 0.8	0.227
p value¶	**<0.001**§	**<0.001**§	**<0.001**§		**<0.001**§	**<0.001**§	
Appearance							
Baseline	2.5 ± 0.7	2.4 ± 0.7	2.5 ± 0.7	0.304	2.4 ± 0.6	2.3 ± 0.6	0.573
Last follow-up‡	3.6 ± 0.9	3.6 ± 0.8	3.6 ± 0.9	0.766	3.5 ± 0.9	3.3 ± 1.0	0.377
p value¶	**<0.001**§	**<0.001**§	**<0.001**§		**<0.001**§	**<0.001**§	
Mental health							
Baseline	3.5 ± 0.9	3.4 ± 0.9	3.6 ± 0.8	0.160	3.5 ± 0.9	3.5 ± 0.8	0.898
Last follow-up‡	3.8 ± 0.8	3.8 ± 0.8	3.8 ± 0.9	0.954	3.9 ± 0.7	3.6 ± 0.9	0.349
p value¶	**0.003**	**0.005**	0.179		0.059	0.561	
Satisfaction							
Baseline	2.8 ± 1.1	2.6 ± 1.1	2.9 ± 1.0	0.252	2.6 ± 1.0	2.8 ± 1.0	0.462
Last follow-up‡	4.3 ± 0.9	4.2 ± 0.9	4.3 ± 0.8	0.814	4.1 ± 0.9	4.3 ± 0.7	0.405
p value¶	**<0.001**	**<0.001**	**<0.001**		**<0.001**	**<0.001**	
Total							
Baseline	2.9 ± 0.6	2.7 ± 0.6	3.0 ± 0.6	**0.030**	2.7 ± 0.6	2.8 ± 0.6	0.420
Last follow-up‡	3.7 ± 0.7	3.6 ± 0.7	3.7 ± 0.7	0.592	3.7 ± 0.7	3.6 ± 0.7	0.928
p value¶	**<0.001**				**<0.001**	**<0.001**	
NRS‡‡							
Back pain†							
Baseline	7.0 ± 2.2	7.6 ± 1.6	6.6 ± 2.5	0.069	7.9 ± 1.3	6.8 ± 2.4	0.128
Last follow-up	3.5 ± 3.0	3.9 ± 3.0	3.2 ± 3.0	0.288	4.1 ± 3.0	2.9 ± 2.7	0.177
p value¶	**<0.001**§	**<0.001**§	**<0.001**§		**<0.001**§	**<0.001**§	
Leg pain**							
Baseline	4.6 ± 3.2	5.4 ± 3.1	4.0 ± 3.1	**0.026**	5.6 ± 2.8	4.9 ± 2.6	0.345
Last follow-up	2.1 ± 2.8	2.1 ± 2.5	2.1 ± 3.0	0.641	1.6 ± 2.1	2.2 ± 3.1	0.867
p value¶	**<0.001**§	**<0.001**§	**0.002**§		**<0.001**§	**0.003**§	

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TABLE 4. Unmatched and matched comparisons of HRQL data at baseline and last follow-up of patients who underwent L4–S1 TLIF versus ALIF

Values are shown as mean ± SD unless indicated otherwise. Boldface type indicates statistical significance ($p < 0.05$).
* Determined with Mann-Whitney U-test or independent-samples t-test.
† Unmatched postoperative data were available for 105 patients.
‡ Minimum 2-year follow-up data were based on radiographic follow-up, and 1-year clinical HRQL data were used for 5 patients.
§ Significant p value with mean score ≥ 1 MCID. MCID values were –12.8 for ODI, +4.9 for PCS, +0.375 for SRS-22r activity, +0.587 for SRS-22r pain, +0.8 for SRS-22r appearance, +0.42 for SRS-22r mental health, –1.2 for NRS back pain, and –1.6 for NRS leg pain. No MCID values are reported for SF-36, SRS-22r total, and SRS-22r satisfaction.[18,24,26]
¶ Values determined at baseline were compared with those determined at last follow-up by using the Wilcoxon signed-rank test or paired t-test.
** Unmatched postoperative data were available for 98 patients.
†† Unmatched postoperative data were available for 101 patients.
‡‡ 1-year data were used for 7 patients.

GCM.[13] However, proper correction of the fractional curve may be challenging because these curves are typically more rigid and "stiffer" than TL/L curves.[4] In addition, pelvic fixation is often performed to support long posterior instrumented deformity correction, but this may increase the risk of complications associated with these complex operations.[3,29–31] Despite these challenges, the importance of adequate fractional curve correction for achieving optimal outcomes after operative adult ASLS management cannot be overstated.[4]

As an adjunct to long-segment posterior instrumented correction, surgeons commonly perform interbody fusion at the caudal lumbar or lumbosacral levels to achieve potential benefits, including disc and foraminal height restoration, low risk of pseudarthrosis, and maintenance of segmental correction.[10,12,30,32–38] However, there is no clear consensus regarding the optimal interbody fusion technique for operative treatment of ASLS. Historically, ALIF was frequently utilized because anterior exposure of the index level can allow for direct release of anterolat-

TABLE 5. Summary of the characteristics of 16 patients with rod fracture on postoperative imaging

Patient No.	IBF	Cage Material*	Year of Index Op	Location of Rod Fracture†	3CO	Index Accessory Rods	Revision Year/Accessory Rods
1	L4–5 & L5–S1 ALIF	Allograft	2009	Unspecified	T11 VCR & cage implantation	No	2010/no
2	L5–S1 TLIF	Titanium	2011	Below L5 bilat	L2 PSO & cage implantation	No	2013/yes
3	L5–S1 TLIF	Titanium	2011	Below rt L4 & lt L2	No	No	No revision
4	L4–5 & L5–S1 TLIF	PEEK	2011	Below lt S1	No	No	No revision
5	L4–5 & L5–S1 TLIF	Titanium	2011	Below rt L5	No	No	No revision
6‡	L4–5 TLIF	Titanium	2011	Below lt L4	No	No	2014§
7	L4–5 & L5–S1 TLIF	Titanium	2013	Unspecified	No	No	No revision
8	L5–S1 TLIF	Titanium	2013	Below L3 bilat	T12 VCR & cage implantation	T11–L2 & L4–S1¶	No revision
9	L4–5 & L5–S1 TLIF	Titanium	2013	Unspecified	No	No	2016 & 2017/yes
10	L4–5 & L5–S1 TLIF	Titanium	2014	Above rt S1 & below lt L5	No	No	No revision
11	L4–5 & L5–S1 ALIF	PEEK	2014	Below L5**	No	No	2017/yes
12	L5–S1 TLIF	Carbon fiber	2014	Below lt L5 & below rt L3	No	No	No revision
13	L5–S1 ALIF	PEEK	2016	Unspecified	No	No	2018/yes
14	L4–5 & L5–S1 TLIF	PEEK	2016	Below L3**	No	No	No revision
15	L4–5 & L5–S1 ALIF	PEEK	2017	Below lt L3	No	No	No revision
16	L4–5 & L5–S1 ALIF	Titanium	2017	Unspecified	No	No	2018/yes

PEEK = polyetheretherketone; PSO = pedicle subtraction osteotomy; VCR = vertebral column resection.
* No statistically significant difference between the percentage of patients treated with titanium TLIF cage and percentage of patients treated with non-titanium TLIF cage ($p = 0.703$).
† Independent review of scoliosis radiographs was performed by T.J.B. Rod fracture location was determined on the basis of its proximity (above vs below) to the nearest ipsilateral pedicle screw.
‡ Only patient who did not undergo iliac fixation in this table; however, 87% of the overall cohort underwent iliac fixation.
§ Unable to determine if revision operation utilized accessory supplemental rod.
¶ One accessory rod spanned right T11–L2, and another accessory rod spanned right L4–S1. Rod fractures developed between these rods.
** Laterality of rod fracture was unclear on anteroposterior imaging.

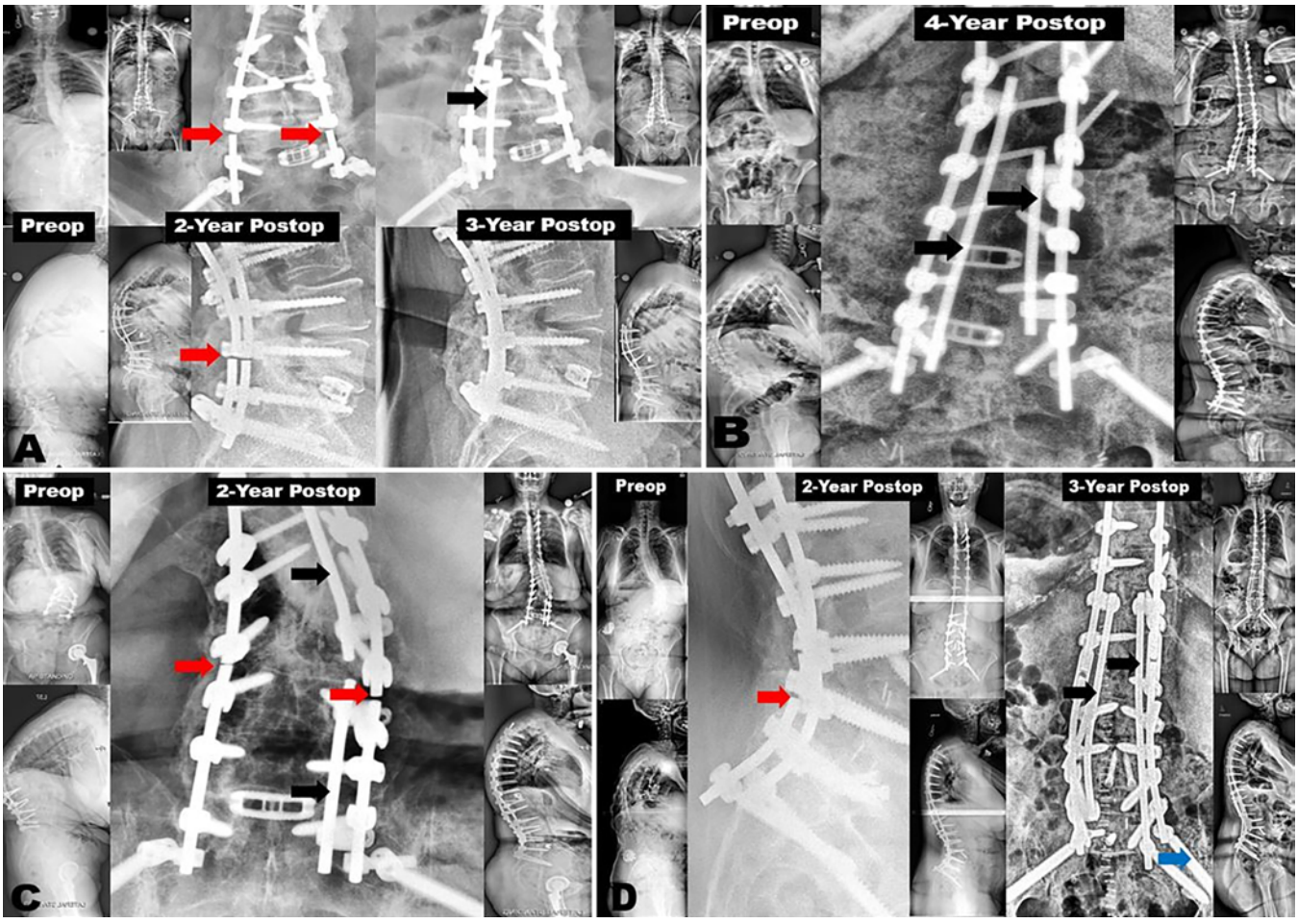

FIG. 2. A: Standing anteroposterior and lateral scoliosis radiographs obtained from patient 2 included in the summary of rod fractures (Table 5). The patient underwent L5–S1 TLIF at the lumbosacral fractional curve. Bilateral rod fractures just below the L5 pedicle screws were noted on 2-year postoperative radiographs (*red arrows*). The patient underwent a revision operation with an accessory supplemental rod spanning the L4–S1 lumbosacral fractional levels (*black arrow*). **B:** Anteroposterior and lateral scoliosis radiographs obtained from patient 9 included in the summary of rod fractures (Table 5). The patient underwent L4–5 and L5–S1 TLIF. Revision surgery for rod fracture was performed, and 2 accessory supplemental rods were utilized to span left L2–S1 and right L3–5 (*black arrows*). **C:** Radiographs obtained from patient 8, who underwent L5–S1 TLIF, show accessory supplemental rods that were utilized during index surgery to span right T11–L2 and right L4–S1 (*black arrow*). Bilateral rod fractures between the accessory rods are noted below the L3 pedicle screws on 2-year postoperative radiographs (*red arrows*). No revision surgery was performed. **D:** Radiographs obtained from patient 11, who underwent L4–5 and L5–S1 ALIF, show rod fracture at L5 (*red arrow*). Revision surgery was performed with bilateral accessory supplemental rods (*black arrows*) that utilized an additional iliac bolt on the right side (*blue arrow*). Note that 5 of 7 revision operations for rod fracture included in Table 5 required novel use of accessory supplemental rods. Figure is available in color online only.

eral bridging osteophytes, sectioning of the anterior longitudinal ligament, more complete discectomy, and larger grafts with increased surface area for arthrodesis.[4,33,35] For example, Jackson et al. described ASLS correction with anterior curve release, discectomy, and anterior interbody fusion by using Dwyer or Zielke instrumentation.[2,3] To maintain long-term correction, the authors suggested that additional anterior fusion may be necessary after posterior Cotrel-Dubousset instrumentation.[3] Since these earlier reports, there have been significant advancements in posterior instrumentation that allow posterior-only correction and anterior column support with TLIF. In comparison with anterior-posterior correction with ALIF, the TLIF technique circumvents the potential need for a vascular access team, avoids potential morbidity associated with intraabdominal exposure (e.g., vascular or visceral injury, ileus), and may reduce operative time.[4,33,35–37,39] However, in comparison with ALIF, the posterior transforaminal interbody approach affords a smaller operative corridor to the index disc space; this may limit discectomy and graft size and lead to potentially higher risks of pseudarthrosis, graft subsidence, and loss of correction.[4]

Although prior outcome studies have compared TLIF with ALIF, many of these studies were limited by single-center design methodology and focused on non-ASLS pathology treated without long posterior instrumented correction.[35–38] Given the frequent use of both these interbody fusion techniques for ASLS, a multicenter investigation with

TABLE 6. Multiple regression modeling of L4–S1 TLIF/ALIF cage data used to predict changes in segmental alignment from preoperation to last follow-up

Cage Parameter	ΔL4–5 Lordosis	ΔL5–S1 Lordosis	ΔL4 Coronal Tilt*	ΔL5 Coronal Tilt*
TLIF cage				
Height, mm	1.5 (0.171)†	0.6 (0.592)‡	–2.2 (**0.011**)	–0.9 (0.176)
Lordosis, °	0.2 (0.854)§	1.6 (0.207)‡	–1.2 (0.076)	–1.0 (0.187)
R^2	0.111	0.103	0.448	0.188
ALIF cage				
Height, mm	–0.5 (0.626)¶	0.8 (0.175)**	0.3 (0.779)	1.0 (**0.029**)
Lordosis, °	0.9 (0.243)¶	0.4 (**0.045**)**	1.3 (0.108)	–0.1 (0.666)
R^2	0.069	0.255	0.256	0.156

Regression coefficients are shown with p values in parentheses. Boldface type indicates statistical significance ($p < 0.05$).
* Segmental coronal tilt was determined on the basis of the slope of the superior endplate of L4 or L5.
† Data were available for 22 patients.
‡ Data were available for 24 patients.
§ Data were available for 23 patients.
¶ Data were available for 28 patients.
** Data were available for 33 patients.

direct comparative analysis was warranted. The current study extracted consecutive patients from a prospectively collected database of patients with ASD. Study inclusion criteria defined the minimum fractional curve as ≥ 10°. This is consistent with other authors who suggested a fractional curve ≥ 10° or ≥ 15° as an indication to include fractional segments in the posterior fusion construct.[5,8,30] Prior to matching, database extraction and application of our study criteria produced balanced groups of TLIF and ALIF patients (44% and 56% of the study cohort, respectively).

Our results demonstrated an approximate 66% rate of lumbosacral fractional correction (fractional curve 20.2° preoperatively vs 6.9° at the last follow-up) for the entire cohort of 106 patients. Matching TLIF and ALIF patients according to number and type of interbody fusion generated subgroups with comparable baseline demographic characteristics, comorbidities, and radiographic measures. Matched results demonstrated similar fractional curve corrections of approximately 67% for TLIF patients and 65% for ALIF patients. In general, this result is consistent with those of the few other published studies of adult scoliosis, which reported fractional correction of approximately 60%.[8,33,40] Most of the other assessed radiographic measures in this study had significantly improved at the last follow-up. Also, we found no statistically significant differences in baseline and follow-up radiographic measurements between the TLIF and ALIF groups. Notably, segmental radiographic correction (L4 tilt, L5 tilt, L4–5 lordosis, L5–S1 lordosis) was comparable between TLIF and ALIF patients.

These results differ from those of some prior reports that suggested ALIF is superior to TLIF for restoring L4–5 and L5–S1 segmental lordosis and overall LL.[35–38] For example, Hsieh et al. reported that TLIF decreased focal lordosis by 0.4° at L4–5 and by 1.1° at L5–S1 and decreased overall LL by 2.2° when performed at L4–5 and by 3° when performed at L5–S1.[35] The authors found that ALIF increased focal lordosis by 8.1° and overall LL by 6.2° when performed at L4–5, and ALIF increased focal lordosis by 9.1° and overall LL by 6.6° when performed at L5–S1.[35] It is important to note that the study by Hsieh et al., as well as many other studies that compare TLIF with ALIF,[36–38] included patients without ASLS and a lumbosacral fractional curve who underwent instrumented correction with short construct lengths (e.g., the study by Hsieh et al. included patients who underwent lumbar fusion at ≤ 3 levels).[35]

Two notable studies compared TLIF with ALIF and focused on ASLS pathology.[32,41] The first study, by Crandall and Revella, compared the outcomes of patients with degenerative lumbar scoliosis who were treated with posterior instrumented correction and additional TLIF or ALIF.[32] Like us, they reported comparable regional deformity correction (i.e., T12–S1 lordosis) in the TLIF and ALIF groups; however, their study did not assess segmental lordosis or lumbosacral fractional curve.[32] The other notable ASLS study by Dorward et al. also reported comparable T12–S1 lordosis correction after TLIF and ALIF in patients who underwent long instrumented fusion.[41] In contrast to our findings, Dorward et al. reported that ALIF created more segmental lordosis at L4–5 and L5–S1 compared with TLIF.[41] Also, Dorward et al. reported significantly greater fractional curve correction in their TLIF group.[41] A potential explanation for these different findings could be related to the different baseline deformities of the TLIF and ALIF groups included in the Dorward et al. study. The ALIF group included patients with more severe SVA but smaller fractional curves compared with those of the TLIF group. Also, our study cohort comprised patients with greater baseline deformity (e.g., SVA, lumbar curve, fractional curve) in comparison with those included in the Dorward et al. study.

There is some debate regarding clinical outcomes after long instrumented deformity correction at the caudal levels with additional TLIF versus those after ALIF. Crandall and Revella found similar improvements in visual analog scale scores for pain and ODI scores between patients who underwent long instrumented correction with TLIF versus ALIF.[32] Dorward et al. also reported similar ODI improvements between their TLIF and ALIF cohorts, but

they also found significantly greater improvement in SRS scores associated with ALIF.[41] The current study results demonstrated that final ODI and PCS scores were inferior in the TLIF group. A potential explanation for these results may be related to differences in complication rates between studies. Both Crandall and Revella and Dorward et al. reported similar complication types and rates for TLIF and ALIF.[32,41] Also, Crandall and Revella demonstrated that major complications, such as nonunion, were associated with less favorable clinical outcomes in both TLIF and ALIF patients.[32] In contrast, we found a significantly higher rate of rod fracture associated with use of TLIF. Furthermore, we think that this may have been a contributing factor to the worse outcome scores in our TLIF group. Note that other studies of ASD have also reported worse clinical outcomes associated with rod fracture.[42,43]

Recent studies in the literature support the use of multiple-rod deformity constructs because of their potential to reduce the occurrence of primary rod fracture.[44,45] In this study, rod fracture was commonly identified at the fractional levels in the caudal lumbar and lumbosacral spine. As such, we believe that it may be beneficial to utilize additional rods (e.g., accessory supplemental rods) to span these fractional levels in patients who undergo long instrumented correction for adult scoliosis. Also, because our study demonstrated a greater rate of rod fracture in the TLIF group than the ALIF group, use of additional rods may be even more important if surgeons choose to perform TLIF instead of ALIF at the fractional level. Of note, another study reported improved arthrodesis with ALIF (in comparison with TLIF) and suggested that this may be related to the use of larger ALIF cages with increased surface area.[4] In this study, we also found that the ALIF cages were larger (greater height and lordosis) than the TLIF cages; therefore, this may partly explain the higher rate of rod fracture among patients treated with TLIF and why it may be important to add additional rods to TLIF constructs used for long instrumented correction of ASLS.

Other important results from the current study include reduced operative time associated with TLIF according to both matched and unmatched analysis. Also, the use of TLIF was associated with a significantly shorter length of hospitalization, but this was not significant after matching. These results are consistent with findings reported by other authors.[36,37,41] Of note, it is possible that the longer operative duration of the ALIF cohort was related to anterior approach/closure, increased time for repositioning between stages (thereby contributing to total time under anesthesia), and/or any additional time related to working with vascular access teams (if used). Next, a unique strength of this study was its more granular analysis that included measurements of the interbody cages. First, we demonstrated the larger height and increased lordosis of the ALIF cages in comparison with those of the TLIF cages. This could be expected from the larger exposure afforded by an anterior approach, in comparison with a more limited posterior transforaminal corridor.[4,33,35] Next, multiple regression modeling demonstrated that TLIF cage height had a significant impact on leveling L4 coronal tilt, whereas ALIF cage lordosis had a significant impact on restoration of lumbosacral lordosis. This could be interpreted as follows: 1) when performing TLIF, use of larger cages may afford improved fractional correction, and 2) when performing ALIF, use of more lordotic cages may afford improved restoration of segmental lordosis. However, note that a paradoxical finding of this study was that a 1-mm increase in L5–S1 ALIF cage height led to a significant increase in L5 coronal tilt by 1.0°. Also, we acknowledge that cage sizes were not standardized between TLIF and ALIF or L4–5 and L5–S1 in this multicenter study. Therefore, although our study provides novel analysis of interbody cage data, final operative decision-making should ultimately be determined according to the surgeon's comfort and experience using various interbody fusion techniques. In addition, other cage details (e.g., anterior-posterior and lateral dimensions) were unavailable for analysis but could be a subject of future investigation.

Other potential limitations of this study include the lack of routine use of postoperative CT for assessment of complications. As such, it is possible that some complications, such as pseudarthrosis, were not detected. Also, for some complications, we acknowledge that it may be difficult to identify the stage (anterior vs posterior) when the complication occurred. However, we used rigorous study methodology with on-site coordinators who assisted with the collection of complication data, and data auditing was regularly performed at a central location to help ensure accuracy. In addition, complications were also collected for the 29 (21.5%) patients who did not achieve the minimum 2-year follow-up, and there does not appear to be a disproportionate rate of complications that could explain loss of follow-up. Therefore, the present study results may represent the most accurate complication rates associated with the use of L4–S1 TLIF and ALIF for long instrumented correction of ASD. Next, our study results may have been limited by selection bias because the study patients were not randomly assigned to their treatment groups. To address this limitation, we propensity matched TLIF and ALIF patients, which produced comparable cohorts for most of the assessed baseline variables. However, some factors, such as preoperative curve flexibility, were unavailable for analysis, and this may have impacted and biased our outcomes. Also, after 1:1 matching, the analysis was likely underpowered to detect a significant difference in length of hospitalization between ALIF and TLIF patients. Finally, the study inclusion criteria defined preoperative baseline deformity as a TL/L curve ≥ 30° and lumbosacral fractional curve ≥ 10°. It is reasonable to assume that most surgeons would include correction of a lumbosacral fractional curve as part of their operative goals;[5,8,30] however, we acknowledge that the operating surgeon's intent or goals of correction cannot be known definitively.

Conclusions

This study provided a multicenter assessment of outcomes and complications associated with use of lumbosacral TLIF and ALIF for operative treatment of ASLS. The results demonstrated comparable fractional curve correction (66.7% for TLIF patients vs 64.8% for ALIF patients), despite use of significantly larger, more lordotic ALIF cages. Our analysis was novel owing to its inclusion and assessment of interbody cage dimensions. TLIF

cage height had a significant impact on leveling L4 coronal tilt, whereas ALIF cage lordosis had a significant impact on restoration of lumbosacral lordosis. Potential advantages of TLIF may include reduced operative duration and length of hospitalization; however, associated HRQL measures were inferior and more rod fractures were detected in TLIF patients compared with ALIF patients.

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Disclosures

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