Analysis of The Correction Capability of Oblique Lumbar Interbody Fusion Approach to Improving The Lenke-Silva Classification in First-Stage MIS Adult Spinal Deformity Corrections

Leo Shaw

Department of Orthopedics, Taichung Veterans General Hospital

Yu-Tsung Lin

Department of Orthopedics, Taichung Veterans General Hospital

Yun-Che Wu

Department of Orthopedics, Taichung Veterans General Hospital

Cheng-Min Shih

Department of Orthopedics, Taichung Veterans General Hospital

Chien-Chou Pan

Department of Orthopedics, Taichung Veterans General Hospital

Kun-Hui Chen

Department of Orthopedics, Taichung Veterans General Hospital

Cheng-Hung Lee (✉ leechenghung298f@gmail.com)

Department of Orthopedics, Taichung Veterans General Hospital

Research Article

Keywords: OLIF, adult spinal deformity, staged surgery, MIS ASD correction

Posted Date: July 15th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-635577/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Abstract

Background

A two-stage minimally invasive surgery (MIS) protocol with oblique lumbar interbody fusion (OLIF) combined with posterior instrumentation is becoming popular in the treatment of adult spinal deformities (ASDs) because of lower complication rates and less blood loss when compared with the open traditional posterior approach. The objective of this study is to determine the efficacy of correction and the causes of suboptimal correction in two-stage OLIF.

Methods

This retrospective study included 27 patients who underwent both two-stage and single-stage OLIF with posterior instrumentation for treatment of ASD. Patients treated with two-stage OLIF were sorted into Group A (Improved Lenke-Silva classification after the first-stage OLIF) and Group B (Unchanged Lenke-Silva classification after the first-stage operation) to evaluate the correction efficacy of OLIF in a two-stage MIS protocol. Statistical analyses were performed to compare the clinical and radiological outcomes. The causes of complications and suboptimal corrections (Group B) in patients treated with the two-stage MIS protocol were analyzed.

Results

All 27 patient patients showed significant improvement ($P < 0.05$) in the visual analog scale, the Oswestry Disability Index, and EuroQol. A total of 14 patient were treated with the two-stage protocol, with ten patients included in group A and four patients with insufficient correction angles included in group B. The radiographic outcome of Group A showed significant corrections ($P < 0.05$) in pelvic tilt, pelvic incidence-lumbar lordosis (PI-LL) mismatch, sagittal vertical axis, and max Cobb angles. In group B, surgical limitations of OLIF were the cause of unsatisfactory correction in two patients because the deformities involved the T-L junction, which was not accessible using the approach. Severe preoperative PI-LL mismatch (41°) and cage subsidence with an anterior endplate fracture were the cause of poor correction in two other patients.

Conclusion

OLIF can provide significant corrections that reduce the need for a Smith-Petersen osteotomy (SPO) or a pedicular subtraction osteotomy (PSO) for additional correction during posterior instrumentation. Deformities involving the T-spine or T-L junction, severe PI-LL mismatches, and cage subsidence are the possible causes of suboptimal corrections with OLIF using the two-stage protocol.

Background

The incidence of adult spinal deformity (ASD) had been increasing as the elderly population grows. The traditional posterior approach for treatment of ASD may cause destabilizing effects on the spine and cause disruption of the posterior tension band.[1] Posterior osteotomies have been considered the standard method for surgical correction of ASD because the procedure can effectively improve coronal and sagittal alignment.[2–4] However, this method comes with a high risk of pseudoarthrosis, instrumentation failure, or rod breakage, and the complication rate can reach as high as 40%.[5, 6]

In the past decade, retroperitoneal approaches, such as anterior or oblique lumbar interbody fusion (ALIF or OLIF), have been developed to minimize the need for extensive dissection and trauma to muscles related to the posterior approach. Minimally invasive surgical (MIS) approaches are playing an increasing role in the treatment of ASD because such approaches spare the patient from severe complications associated with posterior osteotomies.[7–10] The advantages of MIS techniques include decreased blood loss, less postoperative pain, and a shorter length of stay in the hospital. Furthermore, both cadaver and MRI studies published by Davis *et al.* and Molinares *et al.* showed that entrance to the vertebral disc through the oblique lateral corridor is safe and simple to perform.[11, 12] Thus, a variety of operative protocols have been adopted to reduce complications rates. In our hospital, we have been using a two-stage operative protocol over traditional posterior open surgery since 2018. The protocol involves OLIF during the first stage followed by posterior instrumentation in the second stage, where the duration between the stages depends on the patient's physiological status and neurological symptoms.

The purpose of this study is to retrospectively analyze the efficacy of a two-stage OLIF correction and the causes of suboptimal correction or failure using the Lenke-Silva Classification as an objective tool. In previous studies, an MIS correction was considered appropriate for treating cases with relatively mild or moderate ASD, but the ability to achieve sufficient corrections (changes in the Lenke-Silva classification level) and possible factors for failure of corrections when using this approach have not yet been thoroughly analyzed, which also directly affects whether to extend fusion to the thoracic spine (Lenke-Silva level V) or to perform an osteotomy (Lenke-Silva level VI) in the second stage.[2, 13, 14] Our hypothesis is that OLIF could contribute significantly to ASD correction during two-stage MIS surgery.

Material And Methods

Patient enrollment

After approval from the Institutional Review Board (IRB No: CE20218B), we retrospectively reviewed our prospectively collected MIS ASD database for patients who had received staged OLIF (ALIF used for pathologies involving L5-S1) as the approach to ASD correction surgery between May 2018 and June 2021. The inclusion criteria were patients with adult spinal ASDs treated using OLIF or ALIF for correction involving L5-S1 as the main correction method. The exclusion criteria were surgical correction without the use of the OLIF approach, deformities caused by infections or malignancies, patient age less than 20 years old, and incomplete imaging data. A flowchart of the patient enrollment process is provided in Fig. 1. Patients with changes in the Lenke-Silva level

after first-stage surgery were grouped into group A, and patients with unchanged Lenke-Silva levels after first-stage surgery were grouped into group B to assess the ability of OLIF to correct their deformity using the two-stage MIS protocol.

Operative techniques

The surgery protocol for staged ASD correction in this study was OLIF (ALIF was used for pathologies involving L5-S1) for the first stage of surgery, then posterior instrumentation implanted in the second stage of the surgery. There were no strict guidelines for the duration between the first- and second-stage surgeries.

For the first stage of the correction surgery, OLIF procedures were performed depending on the patient's clinical condition. After general anesthesia was administered, the patient was securely braced in the right lateral decubitus position with silicone padding and lateral supports to prevent pressure sores. Before sterile draping, the desired level of correction was mapped out with a mobile C-arm system to ensure the proper approach to the spine. Polyether ether ketone devices with anteroposterior widths of 18 mm or 22 mm were used (6° lordosis cage, CLYDESDALE™ Spinal system, Medtronic, Inc). Robotic assistance (Mazor Robotics Renaissance®) was optional for posterior instrumentation in the second stage.

Functional outcome assessment

Assessments of functional scores were performed preoperatively (Pre-op) and after completion of the staged operation protocol (Pre-op and 1, 3, 6, 12, and 24 months after operation). We used the visual analog scale (VAS) to assess back and leg pain, the Oswestry Disability Index (ODI), and the EuroQoL 5-dimension (EQ-5D). Complications observed during the study period were carefully recorded and classified into major complications and minor complications. We modified the classification methods for complications presented by Xu *et al.*[15] Major complications included vascular injury, deep venous thrombosis, pseudoarthrosis, instrument failure, proximal junctional kyphosis, and proximal junctional failure. Minor complications were approach-related transient left thigh numbness, muscle weakness, cerebrospinal fluid leakage, and superficial infections.

Radiological outcome assessment

Whole spine radiographs of the patients standing in the upright position were obtained under three conditions: preoperative, post-OLIF (For the 2-stage protocol), and post-posterior instrumentation. We measured the following parameters with Surgimap (Nemaris, Inc.) when assessing the radiographs we assessed: the sagittal vertical axis (SVA), the max Cobb angle, coronal balance (coronal C7-plumb line), pelvic incidence (PI), pelvic incidence-lumbar lordosis (PI-LL), and lumbar lordosis (LL). All patients were classified using the Lenke-Silva classification preoperatively, post-OLIF (for the 2-stage protocol), and post-posterior instrumentation.[2]

Statistical analysis

A statistical analysis was completed with IBM SPSS statistics version 23 (IBM Corp., Armonk, New York, USA). Data were presented as mean $\pm$ standard deviation. The functional outcomes were assessed with the Wilcoxon signed-rank test. A paired t-test was used to compare the radiological outcomes of all patients because the normality of the data was confirmed with the Kolmogorov-Smirnov test. The radiological outcomes for group A and group B were analyzed with the Mann-Whitney U test for the continuous variables. For the demographics, the Mann-Whitney U test was used for the continuous variables, and Fisher's exact test was used for the categorical variables.

Results

Demographic Data

In this study, a total of 27 patients (8 men and 19 women) treated with OLIF correction surgery were included. Their average age was 65.2 ± 7.9 years old, and their mean postoperative follow-up duration was 10.1 ± 5.2 months. Twenty-six patients (96.3%) had *de novo* type ASDs, and one patient (3.7%) had a residual-type ASDs. All twenty-seven patients had lumbar main curve deformities. The demographics data are presented in Table 1.

Table 1
Basic demographic of all 27 ASD patients

Age (years)	65.2 ± 7.9
Female (%)	70%
Body mass index (kg/m ²)	26.2 ± 3.5
Type of ASD	
De-novo	26
Residual	1
Main curve type	
Lumbar	27
Follow up time (months)	10.1 ± 5.2
Stage of surgery	
Singe stage	13
Two stage	14
Operation time (total)(hr)	10.0 ± 3.3
Blood loss (total)(ml)	892 ± 552
OLIF + ALIF levels	2.8 ± 0.6
Posterior instrumentation levels	4.2 ± 2.2
Robotic-assisted (n)	15
*ASD: adult spinal deformity, OLIF: oblique lumbar interbody fusion, ALIF: anterior lumbar interbody fusion	

Intraoperative Data

Table 2 provides the intraoperative data for all twenty-seven patients included in this study. Thirteen patients in this study went through single-stage surgery, and fourteen patients received two-stage surgery. The average OLIF/ALIF levels were 2.8 ± 0.6 , and an average of 4.2 ± 2.2 levels of posterior instrumentation were applied. Furthermore, fifteen patients (56%) had robotic-assisted instrumentation. The mean total operating time for all patients was 10.0 ± 3.3 hours, and the average total blood loss was 892 ± 552 ml.

Table 2
Intraoperative Data of all 27 ASD patients

Age (years)	65.2 ± 7.9
Female (%)	70%
Body mass index (kg/m ²)	26.2 ± 3.5
Type of ASD	
De-novo	26
Residual	1
Main curve type	
Lumbar	27
Follow up time (months)	10.1 ± 5.2
Stage of surgery	
Singe stage	13
Two stage	14
Operation time (total)(hr)	10.0 ± 3.3
Blood loss (total)(ml)	892 ± 552
OLIF + ALIF levels	2.8 ± 0.6
Posterior instrumentation levels	4.2 ± 2.2
Robotic-assisted (n)	15
*ASD: adult spinal deformity, OLIF: oblique lumbar interbody fusion, ALIF: anterior lumbar interbody fusion	

Clinical Outcomes

There were statistically significant improvements ($P < 0.001$) between the pre-operative and post-operative scores for VAS-back, VAS-leg, ODI, and EQ-5D; their improvements were 7.2 ± 2.4 to 2.9 ± 1.7 , 6.8 ± 2.6 to 1.4 ± 2.1 , 57.9 ± 9.2 to 33.8 ± 14.0 , and 11.7 ± 0.7 to 8.0 ± 1.4 , respectively. The clinical outcomes are provided in Table 3.

Table 3
Clinical outcomes of all 27 ASD patients

	<i>p</i> #
VAS-back	< 0.001
Pre-OP	7.2 ± 2.4
Final follow up	2.9 ± 1.7
VAS-leg	< 0.001
Pre-OP	6.8 ± 2.6
Final follow up	1.4 ± 2.1
Oswestry disability index	< 0.001
Pre-OP	57.9 ± 9.2
Final follow up	33.8 ± 14.0
EQ-5D	< 0.001
Pre-OP	11.7 ± 0.7
Final follow up	8.0 ± 1.4
*ASD: adult spinal deformity, VAS: visual analogue scale	
#Wilcoxon signed-rank test	

Radiographic Parameters

The radiologic outcomes for the 27 ASD patients are shown in Table 4. The radiological changes in the SVA, max Cobb angle, coronal balance, and PT were 42.2 ± 28.9 to 25.4 ± 26.7 ($P = 0.067$), 21.4 ± 10.8 to 13.8 ± 6.8 ($P < 0.001$), 17.5 ± 19.8 to 11.8 ± 10.2 ($P < 0.001$), and 21.4 ± 8.5 to 19.1 ± 6.6 ($P < 0.001$) preoperatively and at the final follow-up, respectively. Even though there were no significant improvements in the SVA postoperatively, the average SVA was

25.4mm, which was within the normal value. There was significant difference preoperatively and at the final follow-up in PI-LL and LL, 15.2 ± 11.9 to 9.8 ± 9.2 ($P = 0.004$), and 32.0 ± 12.9 to 37.2 ± 9.5 ($P < 0.001$), respectively.

Table 4
Radiologic parameter of all 27 ASD patients

Radiologic parameters		p#
Sagittal vertical axis (mm)		0.067
Pre-OP	42.2 ± 28.9	
Final follow up	25.4 ± 26.7	
Max cobb angle (°)		< 0.01
Pre-OP	21.4 ± 10.8	
Final follow up	13.8 ± 6.8	
Coronal balance (mm)		0.008
Pre-OP	17.5 ± 19.8	
Final follow up	11.8 ± 10.2	
Pelvic tilt (°)		< 0.001
Pre-OP	21.4 ± 8.5	
Final follow up	19.1 ± 6.6	
PI-LL (°)		0.004
Pre-OP	15.2 ± 11.9	
Final follow up	9.8 ± 9.2	
LL (°)		< 0.001
Pre-OP	32.0 ± 12.9	
Final follow up	37.2 ± 9.5	
*ASD: adult spinal deformity, PI: pelvic incidence, LL: lumbar lordosis		
#Paired-T test (normality of the data was confirmed with Kolmogorov-Smirnov test)		

Comparison of the radiological outcomes of Group A and Group B

Ten patients with improved Lenke-Silva levels were included in Group A, and four patients with unchanged Lenke-Silva levels were included in Group B. The rate of successful correction was 71%. The max Cob angle of group A was 22.9 ± 8.6 and 16.4 ± 5.3 ($P = 0.005$) preoperatively and after the first stage OLIF, respectively (Table 6). The PI-LL mismatch was 13.9 ± 14.7 preoperatively, which improved to 3.2 ± 9.6 ($P = 0.005$) after the first stage OLIF. The SVA was 34.7 ± 33.5 mm preoperatively and -0.1 ± 22.3 mm ($P = 0.022$) after the first-stage OLIF. The PT, LL, PI-LL mismatch, SVA, max Cobb angle in group A were significantly improved after the first stage OLIF, where area, group B did not show significant improvement.

Table 6
Radiographic outcome of Group A (n = 10, Lenke-Silva level changed after 1st stage surgery) and Group B (n = 4, Lenke-Silva level unchanged after 1st stage surgery) after 1st stage surgery

	Group A (n = 10)	Group B (n = 4)	p#
PT			
Pre-OP	18.9 ± 8.9	29.2 ± 12.5	0.188
Post 1st stage	13.6 ± 4.8	23.0 ± 6.4	0.014
p&	0.028	0.144	
PI			
Pre-OP	44.7 ± 7.8	51.7 ± 6.9	0.240
Post 1st stage	43.6 ± 8.7	51.5 ± 6.3	0.142
p&	0.314	1.000	
LL			
Pre-OP	30.8 ± 13.7	30.4 ± 18.2	1.000
Post 1st stage	40.4 ± 12.0	36.5 ± 4.3	0.733
p&	0.007	0.465	
PI-LL mismatch			
Pre-OP	13.9 ± 14.7	21.2 ± 13.2	0.304
Post 1st stage	3.2 ± 9.6	15.0 ± 4.8	0.054
p&	0.005	0.465	
SVA (mm)			
Pre-OP	34.7 ± 33.5	62.3 ± 41.2	0.304
Post 1st stage	-0.1 ± 22.3	57.0 ± 39.4	0.036
p&	0.022	0.465	
Max Cobb angle			
Pre-OP	22.9 ± 8.6	22.7 ± 20.5	0.374
Post 1st stage	16.4 ± 5.3	16.2 ± 16.3	0.454
p&	0.005	0.068	
Coronal balance (mm)			
Pre-OP	11.8 ± 8.2	30.4 ± 23.4	0.188
Post 1st stage	13.9 ± 9.9	16.4 ± 10.0	0.733
p&	0.445	0.144	
*PT: Pelvic tilt, PI: pelvic incidence, LL: lumbar lordosis, SVA: sagittal vertical axis			
#Mann-Whitney U test for continuous variables			
&Wilcoxon signed-rank test for paired continuous data			

Complications

The overall complication rate was 37% (ten of the twenty-seven patients); major complications occurred in four of the twenty-seven patients (14.8%), and minor complications occurred in six of the twenty-seven patients (22.2%). No patients in this study required revision surgery (Table 7).

Table 7
Major and minor Complications

Complication types	N (%)	Details	Treatment and Prognosis
Major			
Vascular injury	1 (3.7%)	Inferior vena cava injury	Repair insitu by CVS, no complications
Deep venous thrombosis	0	None	None
Pseudoarthrosis	0	None	None
Instrument failure	0	None	None
Proximal junctional kyphosis	2 (7.4%)	1. Occurred 14M after operation 2. Screw pullout was observed 2M after opeartion	Continued follow-up, no deterioration
Proximal junctional failure	1 (3.7%)	1. Kyphosis of 37° were noted, there were no symptoms	Continued follow-up, no deterioration
Minor			
Numbness	4 (14.8%)	Transient Lt thigh paresthesia	Recovery within 3 months
Weakness	0	None	None
Cerebrospinal fluid leak	0	None	None
Superficial infection	2 (7.4%)	Stitch abcess formations were found during follow-up	Debridement with drainage and oral antibiotic treatment for 6 weeks.
Revision surgery	0	None	None

Analysis of suboptimal correction

In terms of the patient characteristics of group A and B, there were no significant differences in age, gender, and BMI. There were also no significant between-group differences in type of ASD, preoperative Lenke-Silva classification level, main curve type, sagittal and coronal alignment, or convexity. (Table 5).

Table 5
Demographic of Group A (n = 10, Lenke-Silva level changed after 1st stage surgery) and Group B (n = 4, Lenke-Silva level unchanged after 1st stage surgery)

	Group A (n = 10)	Group B (n = 4)	p#
Age (years)	66.9 ± 7.9	69.5 ± 9.6	0.635
Female (%)	60%	50%	0.594
Body mass index (kg/m ²)	27.7 ± 3.1	27.2 ± 5.8	0.635
Type of ASD			0.286
De-novo	10	3	
Residual	0	1	
Lenke-Silva classification level			
Pre-OP			0.336
III	5	0	
IV	1	1	
V	2	2	
VI	2	1	
Post 1st stage surgery			0.021
II	7	0	
III	2	0	
IV	1	1	
V	0	2	
VI	0	1	
Main curve type			
Lumbar	10	4	
Apex			
T12-L1	2	0	
L1-L2	2	0	
L2	1	0	
L2-L3	4	4	
L4-L5	1	0	
Convexity			0.594
Concave	6	2	
Convex	4	2	
OLIF segments(mean)	27(2.7)	12(3)	0.454
ALIF segments(mean)	3(0.3)	1(0.25)	1.000
Posterior fusion levels	4.9	5.0	1.000
Fusion to T-spine %(n)	30%	25%	0.689
*ASD: adult spinal deformity, OLIF: oblique lumbar interbody fusion, ALIF: anterior lumbar interbody fusion			
#Mann-Whitney U test for continuous variables and Fisher exact test for categorical variables			

In Table 8. The causes of suboptimal corrections in four patients were carefully analyzed. In group B, the approach with OLIF was the main cause of unsatisfactory corrections in two patients (2/4, 50%) because the deformities involved the T-L junction, which was not accessible using the approach. Severe preoperative PI-LL mismatches (41°) and cage subsidence with anterior endplate fractures were the cause of poor corrections in two patients. Patient A had kyphosis located at the T-L junction (T10-L2 kyphosis: 21°), which was impossible to correct, and L1/2 was difficult to access and reconstruct using the OLIF approach. For patient B, the major curve was located at the TL-L junction, and the patient had residual type ASD with a stiff curve of L1/2 and L2/3 (L1-L3 Cobb angle from 35° to 34°). In this case, the disc height of L1/2 was difficult to restore with OLIF because of blockage by the rib cage due to convex bending

to the left side. In patient C, there was unsuccessful correction of lumbar kyphosis because of a severe preoperative PI-LL mismatch with insufficient change in LL (6° - $>30^{\circ}$). In patient D, correction of SVA failed (post 1st stage SVA: 96mm) because of cage subsidence due to an endplate fracture.

Table 8
Analysis of four group B patients for the possible cause of failure correction in first stage surgery

		Pre-OP												
		Age	Gender	Lenke-Silva	Type of ASD	Curve apex	Curve side	Max Cobb(°)	Coronal balance (mm)	SVA (mm)	PI(°)	Pelvic tilt(°)	PI-LL(°)	First stage surgery
Patient factors	Patient A	74	Male	V	De-novo	L2-L3	Right	15	55	101	45	23	19	L2345 OLIF
	Comment	Failure correction of SVA (post 1st stage SVA: 96mm) with acceptable PI-LL correction (post 1st stage PI-LL: 8°)												
	Possible cause	1. Severe T12-L1, L1-L2 DJD change with TL kyphosis (T10-L2 kyphosis: 21°) 2. L12 was difficult to access in OLIF approach												
	Patient B	56	Female	VI	Residual	L2-L3	Left	53	41	41	60	27	13	L2345 OLIF
	Comment	Failure correction of Cobb angle (post 1st stage cobb: 41°)												
	Possible cause	1. Residual type ASD with L12 and L23 stiff curve (side bending view L1-L3 cobb angle from 35° to 34°) 2. L12 was difficult to access in OLIF convex side approach (blocked by rib cage)												
	Patient C	78	Male	IV	De-novo	L2-L3	Left	10	25	15	47	47	41	L2345 OLIF + L5S1 ALIF
	Comment	Failure correction of lumbar kyphosis (post 1st stage PI-LL: 17°)												
	Possible cause	1. Severe pre-OP PI-LL mismatch with insufficient LL change (6°->30°) 2. Pre-OP L45 kyphosis: may consider ACR												
Technique factor	Patient D	70	Female	V	De-novo	L2-L3	Right	12	1	92	54	19	13	L2345 OLIF
	Comment	Failure correction of SVA (post 1st stage SVA: 96mm)												
	Possible cause	1. L23 cage subsidence with endplate fracture (36% height, L23 segmental lordosis 16°->9°) 2. Failure of LL restoration: PI-LL 13°->17°												
*ASD: adult spinal deformity, SVA: sagittal vertical axis, PI: pelvic incidence, LL: lumbar lordosis, OLIF: oblique lumbar interbody fusion, ALIF: anterior lumbar interbody fusion, ACR: anterior column release														

Discussion

In recent years, minimally invasive retroperitoneal approaches such as OLIF have been recognized as an alternative MIS choice for the treatment of ASDs.[13, 14, 16] Such approaches can achieve a correction rate comparable to that of a posterior osteotomy through restoration of disc height and result in lower complication rates and reduced blood loss.[17–19] In our study, 14 patients with ASD were treated using a 2-stage MIS protocol, and 10 patients (10/14, 71.4%) achieved effective correction of coronal and sagittal plane deformity after first stage OLIF (Fig. 2). Overall, there was less blood loss, and the rate of major complications in patients treated with the 2-stage MIS protocol was lower than with a posterior osteotomy.

Kim *et al.* demonstrated that OLIF could be an effective approach for ASD correction in patients with severe sagittal deformity.[20] The author used an L1 to S1 oblique retroperitoneal approach (OLIF) in the treatment of 32 patients with ASD. The mean SVA decreased from 13.6 cm before surgery to 2.9 cm at the final postoperative follow-up; LL increased from 5.8° before surgery to 46.5° at the final postoperative follow-up, and the Cobb angle improved from 21.6° before surgery to 9.6° at the final postoperative follow-up. The mean preoperative PI-LL mismatch in these patients was 44.5° . Yang *et al.* used OLIF combined with unilateral posterior instrumentation through a Wiltse approach to treat degenerative lumbar scoliosis and achieved significant correction of the coronal and sagittal plane, where the post-operative MRIs showed there was significantly increased cross-sectional dural sac area.[21] In treating a severe sagittal deformity, greater correction efficacy can be achieved with lateral lumbar interbody fusion (LLIF) combined with the anterior column resection (ACR) technique.[17] Leveque *et al.* compared LLIF combined with ACR(LLIF-ACR) to PSO in treating patients with severe PI-LL mismatches.[22] Their results showed comparable correction rates among these two groups, with lower pseudoarthrosis and re-operation rates due to pseudoarthrosis in the LLIF-ACR group. Additionally, the results of a study conducted by Li *et al.* indicated that the use of LLIF-ACR or a hyperlordotic cage can increase the correction rate in the first stage of MIS correction.[16]

Studies on possible causes and risk factors of correction failure are scarce.[16] In the present study, 10 of the 14 patients who underwent staged surgery (71%) achieved a change in the Lenke-Silva classification level (Table 4) in the first stage, effectively reducing the need for fusion to the thoracic spine and posterior osteotomy in the second stage, and the correction rates were similar to those of previous studies.[2, 16] There were four patients in which ineffective

correction in the first stage was not achieved (Table 6). Their post-first stage Lenke-Silva classification levels were, IV, V, and VI. The causes were classified as patient factors in three cases and as surgical technique factors in one case. Patient A had severe degeneration of T12-L1 and L1-2 at the thoracolumbar (T-L) junction, which led to kyphosis of the T-L junction (T10-L2 kyphosis: 21°). However, T12-L1 and the L1-2 disk space were impossible to approach through OLIF. After using the OLIF approach to the L2-3, L3-4, and L4-5 during the first-stage operation, the PI-LL mismatch was improved from 19° to 8° post-operatively. However, there was still focal kyphosis of the T-L junction, and global alignment could not be restored to the normal range. Thus, we believe for patients with deformities involving the T-L junction, spinal fusion must be done because deformities in the T-L junction cannot be corrected with OLIF. Patient B was a case of residual type ASD (Fig. 3), in which the main curve was at the T-L junction. Patient B had stiff coronal plane scoliosis curves at L1-2 and L2-3. The left side was the convex side, and the OLIF approach to the L1-2 disc from the left side was blocked by the rib cage. Therefore, the degree of Cobb angle correction in the first stage was not ideal. These two cases of suboptimal correction implied that MIS correction using the OLIF approach is insufficient for deformities involving the T-L junction or the T-spine. Patient C had severe lumbar kyphosis (PI-LL: 41°) due to multilevel lumbar disc collapse. Despite the increment of the LL by 24° after performing OLIF at L2-3, L3-4, L4-5, and ALIF at L5-S1, there was still a PI-LL mismatch of 17° after the first stage surgery; therefore, a posterior osteotomy was still required to achieve optimal lumbar lordosis. Although previous studies have suggested that OLIF is more suitable for management of relatively minor deformities as compared to other alternatives (SVA < 60 mm and PI-LL < 30°), we believe OLIF may also be suitable for achieving sagittal alignment correction in patients with lumbar kyphosis if a hyperlordotic cage or LLIF-ACR is used.[13, 14, 16] Patient D had a global imbalance with a preoperative SVA of 92 mm, where, after surgery, L2-3 segmental lordosis changed from 16° preoperatively to only 9° after the first-stage operation due to L2-3 cage subsidence (36% of the vertebral height), making correction of lumbar lordosis and global imbalance impossible (Fig. 4). This risk factor was also cited in a study by Li *et al.* In this patient, the cage was placed in the anterior third of the disc space, where an anterior endplate fracture cause more significant loss of lumbar lordosis.[16] In the future, a larger prospective study is needed to validate the risk factors for failure of MIS OLIF correction.

Limitations

Our institution has used OLIF as the MIS approach for correction of ASD since 2018. However, this retrospective study involved a relatively small sample size, and a subsequent statistical analysis of specific risk factors could not be conducted. We focused on patients who did not achieve satisfactory correction after the first stage. These patients were individually investigated to determine the possible factors leading to failure of correction. In the future, we plan to conduct a larger prospective study to analyze the factors contributing to the failure of MIS correction of ASD. The present study had a relatively short follow-up period. However, some complications, such as proximal junctional kyphosis or proximal junctional failure, could appear after a longer follow-up period. These complications also affect alignment and functional outcomes and will also be included in our future studies with long-term follow up.

Conclusions

OLIF can provide significant corrections that reduce the need for a SPO or a PSO for additional correction during posterior instrumentation. Deformities involving the T-spine or T-L junction, severe PI-LL mismatches, and cage subsidence are the possible causes of suboptimal corrections with OLIF using the two-stage protocol.

Abbreviations

ACR: Anterior column resection

ALIF: Anteriorlumbar interbody fusion

ASD: Adult spinal deformity

EQ-5D: EuroQoL 5-dimension

LL: Lumbar lordosis

LLIF: Lateral lumbar interbody fusion

LLIF-ACR: LLIF combined with ACR

MIS: Minimally invasive surgery

ODI: Oswestry Disability Index

OLIF: Oblique lumbar interbody fusion

PI: Pelvic incidence

PI-LL: Pelvic incidence-lumbar lordosis

PSO: Pedicular subtraction osteotomy

SPO: Smith-Petersen osteotomy

SVA: Sagittal vertical axis

T-L: Thoracolumbar

VAS: Visual analog scale

Declarations

Ethics approval

This study was conducted after approval from the Institutional Review Board of Taichung veterans general hospital (IRB No: CE20218B)

Consent to participate

This study was conducted with the approval of the patients included in this study.

Consent for publication

This study was conducted under the consent of the patients included in this study.

Availability of data and material

Data and materials are available from the corresponding author under at a reasonable request.

Conflicts of interest/Competing interests

The authors declare that they have no competing interests.

Funding

Not applicable.

Authors' contributions

The authors Leo Shaw and Yu-Tsung Lin contributed equally to this work. Conception and design, YC W, CH Lee and YT Lin; methodology, CH Lee, YT Lin and Leo Shaw; data curation, KH Chen, CC Pan and CM Shih; manuscript writing, YT Lin and Leo Shaw. All authors reviewed the manuscript.

Acknowledgement

The authors Leo Shaw and Yu-Tsung Lin contributed equally to this work.

References

1. Tormenti MJ, Maserati MB, Bonfield CM, Okonkwo DO, Kanter AS: **Complications and radiographic correction in adult scoliosis following combined transpoas extreme lateral interbody fusion and posterior pedicle screw instrumentation.** *Neurosurg Focus* 2010, **28**(3):E7.
2. Silva FE, Lenke LG: **Adult degenerative scoliosis: evaluation and management.** *Neurosurg Focus* 2010, **28**(3):E1.
3. Buell TJ, Chen CJ, Nguyen JH, Christiansen PA, Murthy SG, Buchholz AL, Yen CP, Shaffrey ME, Shaffrey CI, Smith JS: **Surgical correction of severe adult lumbar scoliosis (major curves $\geq 75^\circ$): retrospective analysis with minimum 2-year follow-up.** *J Neurosurg Spine* 2019:1–14.
4. Ayhan S, Aykac B, Yuksel S, Guler UO, Pellise F, Alanay A, Perez-Grueso FJ, Acaroglu E: **Safety and efficacy of osteotomies in adult spinal deformity: what happens in the first year?** *Eur Spine J* 2016, **25**(8):2471–2479.
5. Shaw R, Skovrlj B, Cho SK: **Association Between Age and Complications in Adult Scoliosis Surgery: An Analysis of the Scoliosis Research Society Morbidity and Mortality Database.** *Spine (Phila Pa 1976)* 2016, **41**(6):508–514.
6. Skovrlj B, Cho SK, Caridi JM, Bridwell KH, Lenke LG, Kim YJ: **Association Between Surgeon Experience and Complication Rates in Adult Scoliosis Surgery: A Review of 5117 Cases From the Scoliosis Research Society Database 2004–2007.** *Spine (Phila Pa 1976)* 2015, **40**(15):1200–1205.
7. Fan S, Hu Z, Zhao F, Zhao X, Huang Y, Fang X: **Multifidus muscle changes and clinical effects of one-level posterior lumbar interbody fusion: minimally invasive procedure versus conventional open approach.** *Eur Spine J* 2010, **19**(2):316–324.
8. Fessler RG, O'Toole JE, Eichholz KM, Perez-Cruet MJ: **The development of minimally invasive spine surgery.** *Neurosurg Clin N Am* 2006, **17**(4):401–409.
9. Abe K, Orita S, Mannoji C, Motegi H, Aramomi M, Ishikawa T, Kotani T, Akazawa T, Morinaga T, Fujiyoshi T *et al*: **Perioperative Complications in 155 Patients Who Underwent Oblique Lateral Interbody Fusion Surgery: Perspectives and Indications From a Retrospective, Multicenter Survey.** *Spine (Phila Pa 1976)* 2017, **42**(1):55–62.
10. Smith JS, Shaffrey CI, Bess S, Shamji MF, Brodke D, Lenke LG, Fehlings MG, Lafage V, Schwab F, Vaccaro AR *et al*: **Recent and Emerging Advances in Spinal Deformity.** *Neurosurgery* 2017, **80**(3S):S70-S85.
11. Molinares DM, Davis TT, Fung DA: **Retroperitoneal oblique corridor to the L2-S1 intervertebral discs: an MRI study.** *J Neurosurg Spine* 2016, **24**(2):248–255.
12. Davis TT, Hynes RA, Fung DA, Spann SW, MacMillan M, Kwon B, Liu J, Acosta F, Drochner TE: **Retroperitoneal oblique corridor to the L2-S1 intervertebral discs in the lateral position: an anatomic study.** *J Neurosurg Spine* 2014, **21**(5):785–793.

13. Mummaneni PV, Park P, Shaffrey CI, Wang MY, Uribe JS, Fessler RG, Chou D, Kanter AS, Okonkwo DO, Mundis GM *et al*: **The MISDEF2 algorithm: an updated algorithm for patient selection in minimally invasive deformity surgery.** *J Neurosurg Spine* 2019, **32**(2):221–228.
14. Eastlack RK, Mundis GM, Jr., Wang M, Mummaneni PV, Uribe J, Okonkwo D, Akbarnia BA, Anand N, Kanter A, Park P *et al*: **Is There a Patient Profile That Characterizes a Patient With Adult Spinal Deformity as a Candidate for Minimally Invasive Surgery?** *Global Spine J* 2017, **7**(7):703–708.
15. Xu Z, Li F, Chen G, Chen Q: **Reassessment System and Staged Surgical Strategy with Minimally Invasive Techniques for Treatment of Severe Adult Spinal Deformities.** *World Neurosurg* 2019, **126**:e860–e868.
16. Li H, Xu Z, Li F, Chen Q: **Does Lateral Lumbar Interbody Fusion Decrease the Grading of Lenke-Silva Classification and Determine the Optimal Fusion Level in Severe Adult Degenerative Scoliosis?** *World Neurosurg* 2020, **139**:e335–e344.
17. Xu DS, Paluzzi J, Kanter AS, Uribe JS: **Anterior Column Release/Realignment.** *Neurosurg Clin N Am* 2018, **29**(3):427–437.
18. Than KD, Park P, Tran S, Mundis GM, Fu KM, Uribe JS, Okonkwo DO, Nunley PD, Fessler RG, Eastlack RK *et al*: **Analysis of Complications with Staged Surgery for Less Invasive Treatment of Adult Spinal Deformity.** *World Neurosurg* 2019, **126**:e1337–e1342.
19. Katz AD, Singh H, Greenwood M, Cote M, Moss IL: **Clinical and Radiographic Evaluation of Multilevel Lateral Lumbar Interbody Fusion in Adult Degenerative Scoliosis.** *Clin Spine Surg* 2019, **32**(8):E386–e396.
20. Kim KT, Jo DJ, Lee SH, Seo EM: **Oblique retroperitoneal approach for lumbar interbody fusion from L1 to S1 in adult spinal deformity.** *Neurosurg Rev* 2018, **41**(1):355–363.
21. Yang SL, Liu XY, Ma R, Zhang JQ, Liang SM, Chen Z, Pan Z, Ma ZJ, Ding XL, Kang Y *et al*: **Treatment of Degenerative Lumbar Scoliosis with Oblique Lumbar Interbody Fusion in Conjunction with Unilateral Pedicle Screw Fixation via the Wiltse Approach.** *Orthop Surg* 2021.
22. Leveque JC, Yanamadala V, Buchlak QD, Sethi RK: **Correction of severe spinopelvic mismatch: decreased blood loss with lateral hyperlordotic interbody grafts as compared with pedicle subtraction osteotomy.** *Neurosurg Focus* 2017, **43**(2):E15.

Figures

Figure 1

Flowchart of the patient enrollment process

Figure 2

Case of successful correction This 61 y/o female was diagnosed with degenerative kyphoscoliosis with PO coronal Cobb angle of 36.3° (2A), severe PI-LL mismatch of 28.2° and high pelvic tilt of 25.1° (2B). PO LS level was VI. After the first stage operation (L23, L34 and L45 OLIF), the LS level was improved to level III with improvement of coronal Cobb angle to 18.9° (2C), PI-LL mismatch to 9.3° , PT to 13.2° and SVA to 3.7mm (2D). Further posterior osteotomy or extensive fusion to T-spine were unnecessary in the second stage operation. Posterior instrumentation through Wiltse approach was done (2E and 2F), with further improvement of Cobb angle to 9° and SVA to -13.2mm after the second stage operation. PO: Pre-operative, PI-LL: Pelvic incidence-Lumbar lordosis, LS: Lenke-Silva classification.

Figure 3

Case of suboptimal correction This 56 y/o female was a case of residual type ASD (3A and 3B) in which the main curve was at the thoraco-lumbar junction (Cobb angle: 53°). There were stiff coronal plane scoliosis curves at L1-2 and L2-3(3C and 3D). Flexion-extension X-ray showed convexity at the left side. (3E and 3F) The access to the L1-2 disc space through left side OLIF approach was blocked by the rib cage due to the convexity of left side. Therefore, the correction of coronal plane Cobb angle was less than ideal (Cobb angle: 41°)(3G and 3H). The level of LS remained at level VI after the first stage OLIF correction. Therefore, posterior facetectomy and extended fusion to T-spine were required in the second stage operation. ASD: Adult spinal deformity, TL: Thoraco-lumbar, LS: Lenke-Silva classification.

Figure 4

This 70 y/o female was a case of ASD with severe sagittal imbalance (SVA=92mm, PI-LL=13 degree)(4A and 4B). L23, L34 and L45 OLIF correction was done in the first stage operation(4C and 4D). However, L2 lower endplate was violated during operation and endplate fracture with cage subsidence was occurred after operation, which caused 7° loss of segmental lordosis. Therefore, LL and SVA restoration were failed after first stage correction and the LS level was remained at level V after first stage correction, because LL and SVA restoration were ineffective. Extended posterior fusion to T-spine was necessary in the second stage operation to achieve optimal fusion. ASD: Adult spinal deformity, LL: Lumbar lordosis, SVA: Sagittal vertical axis, LS: Lenke-Silva classification.