CLINICAL ARTICLE

Applications of the Crenel Lateral Interbody Fusion Procedure in Treatment for Adjacent Segments Degeneration of the Lumbar Spine

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Abstract

Objective: To observe the clinical and radiological effect of crenel lateral interbody fusion (CLIF) procedure in the management of lumbar spine adjacent segment degenerative (ASD).

Methods: Thirty-seven patients with lumbar spine ASD who underwent the CLIF procedure between June 2018 and December 2019 were included in the study. There were 13 males and 24 females, with a mean age of 64.30 ± 5.92 years. The VAS score of the back (VAS_Back) and legs (VAS_Leg), Oswestry Disability Index (ODI) score, the height of the intervertebral space (HIS), the height of the intervertebral foramen (HIF), the cross-sectional area (CSA) of the vertebral canal, segmental lordosis (SL), and lumbar lordosis (LL) were recorded before the operation, 2 weeks after the operation, 3 months after the operation, and at the last follow-up respectively. Clinical and radiological outcomes before and after the surgery were compared, and correlation and regression analyses were performed.

Results: There were no vascular and nerve-related complications during the operation. The average follow-up time was 16.63 ± 4.24 months. The median of both VAS_Back and VAS_Leg was 7 before surgery and 1 at the last follow-up. Meanwhile, the average preoperative ODI score, HIS, HIF, CSA of the vertebral canal, LL, and SL was (67.48 ± 7.17) %, (4.80 ± 0.73) mm, (12.95 ± 2.07) mm, (59.52 ± 9.22) mm^2, (37.22 ± 5.92)° and (4.78 ± 1.99)°, respectively. At the final follow-up, ODI score, HIS, HIF, CSA of the vertebral canal, LL, and SL was (7.07 ± 2.66) %, (9.44 ± 0.61) mm, (17.30 ± 1.90) mm, (70.49 ± 8.95) mm^2, (44.67 ± 6.38)° and (13.44 ± 3.27)°, respectively. In the VAS_Back, VAS_Leg, ODI score, LL, SL, HIS, HIF, and CSA of the vertebral canal, the difference between preoperative and 2 weeks after the operation, 3 months after the operation, and the last follow-up were statistically significant ($P < 0.05$). However, the difference was not statistically significant between each time point after the operation in the CSA of the vertebral canal, LL, and SL ($P > 0.05$). Nonetheless, the difference was statistically significant in ODI between each time point after the operation ($P < 0.05$). VAS_Leg was associated with HIS, HIF, and CSA of the vertebral canal, while LL and SL were risk factors for low back pain.

Conclusion: Crenel lateral interbody fusion is an effective procedure in the management of lumbar ASD. Not only was the postoperative swift recovery due to minimal invasion, but also adequate LL and SL were achievable.

Key words: Adjacent segment degenerative (ASD); Crenel lateral interbody fusion (CLIF); Lumbar lordosis (LL); Modified lateral lumbar interbody fusion; Segmental lordosis (SL)

Introduction

Spinal fusion has now become the standard treatment for symptomatic degenerative disc diseases. However, spinal fusion increases the mechanical stress and segmental mobility of adjacent segments, thereby increasing the incidence of adjacent segment degenerative disease (ASD).[1] A study with an average follow-up of 28.6 months showed that the total incidence of ASD after decompression and fusion of adult spondylolisthesis

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was 11.7%.[2] Higher BMI, preoperative intervertebral disc degeneration in adjacent segments, and intraoperative upper facet joint invasion are known factors for ASD.[3] Approximately 24% of patients with lumbar ASD underwent revision surgery.[4]

At present, the most commonly used revision surgery is posterior laminectomy and decompression, expanding the fixed and fused segment.[5] Although posterior lumbar revision surgery can considerably relieve pain and other symptoms in the long term,[6] it still involves obvious drawbacks. The incidence of complications such as surgical site infection, blood loss, paraspinal muscle atrophy and dysfunction, and dural injury during posterior revision surgery is as high as 40%.[5,7,8] In 2006, Ozgur *et al.*[9] reported a direct lateral or extreme lateral interbody fusion technique (DLIF/XLIF), which uses a lateral approach to directly split the psoas major to expose the interbody space without injury to the posterior structure of the spine. The mechanism of lateral lumbar interbody fusion is to expand the area of the spinal canal and intervertebral foramen by opening the interbody space, to achieve indirect decompression.[10] However, this approach results in the possibility of severe psoas injury, femoral nerve injury, and reverse ejaculation.[11] The recently proposed modified lateral lumbar interbody fusion, named crenel lateral interbody fusion (CLIF), is an innovative type of lateral lumbar interbody fusion.[12] This procedure is performed with a single incision, through the safe working area of the psoas major, combined with specially designed retractors and C-ring, which dramatically reduces complications associated with the surgical approach.[12] However, the clinical and radiological outcomes of CLIF procedure in the treatment of lumbar ASD have not been fully elucidated.

Herein, we compared clinical and radiological outcomes before and after the CLIF procedure for lumbar ASD. Our research questions included the following points. (i) Can CLIF procedure for the management of lumbar ASD achieve satisfactory clinical outcomes? (ii) Are changes in lumbar radiological parameters associated with improved clinical outcomes after CLIF procedure? (iii) What are the effects of CLIF procedure of lumbar ASD on the sagittal curvature of the lumbar spine?

Materials and Methods

Inclusion Criteria and Exclusion Criteria

This was a retrospective study, 37 patients with lumbar spine ASD who underwent CLIF procedure from June 2018 to June 2019 in our hospital were included in the study. This study was approved by the Institutional Review Board of our institution (KY-2019-009-01) and each patient signed an informed consent form. Inclusion criteria: (i) Over 18 years old; (ii) one level CLIF procedure was performed; and (iii) follow-up was over 6 months. Exclusion criteria: (i) severe osteoporosis (dual-energy X-ray absorptiometry was employed to measure BMD, $T \leq -2.5$ was defined as osteoporosis); (ii) compared with tumors, infections or other spinal diseases; (iii) trauma was experienced during follow-up; and (iv) radiological data was incomplete.

Surgery Process

Anesthesia and Position

According to the method reported in the literature,[12] all cases were observed with a neuroelectrophysiological monitor. The CLIF procedure was performed under general anesthesia with endotracheal intubation. After successful anesthesia, the patient was placed in the standard right decubitus position, with the waist raised and the lower limbs slightly flexed, and the target disc was fluoroscopically positioned and marked on the body surface.

Approach and Exposure

As shown in Fig. 1, the surgical area was routinely disinfected. The skin and subcutaneous tissue were then opened, layer by layer, along the body surface markings. Next, the external oblique, internal oblique, and transverse abdominal muscles were bluntly separated to expose the retroperitoneal space. The extraperitoneal fat was retracted, and the peritoneum was pulled to expose the psoas major. Caution was taken to protect the genital femoral nerve. Afterward, the psoas major was split at the anterior and middle 1/3, and finally, the target disc was located and confirmed by fluoroscopy.

Intervertebral Space Treatment

After fluoroscopy was successfully performed, three retractable blades were inserted and fixed to the "C"-shaped ring to establish a working channel. A point worth noting is that half-screw fixation screws were not utilized during the process. Next, the ipsilateral annulus fibrosus was cut, a section of the degenerative nucleus pulposus was taken out, and the cartilage endplates on the upper and lower surfaces of the vertebral body were scraped off. The contralateral annulus was dissected after the above procedures were accomplished, then the intervertebral space was dilated step by step with distractors.

Cage Implantation

The appropriate size of the cage (Sanyou, Shanghai, China) was selected according to the height of the intervertebral space (HIS). With allogeneic bone filled in it, the cage was implanted in the intervertebral space. Lastly, the incision was flushed and closed.

Postoperative Treatment

First-generation cephalosporins were administered within 48 h after surgery to prevent infection. After waking up from anesthesia, patients were instructed to exercise in bed. Meanwhile, patients were allowed to wear a brace to get out of bed 2 days after surgery, and the brace was worn for 2-3 months after surgery. After the surgical procedure, patients with osteoporosis were routinely managed with anti-osteoporotic therapy, including calcium, vitamin D, and bisphosphonates.

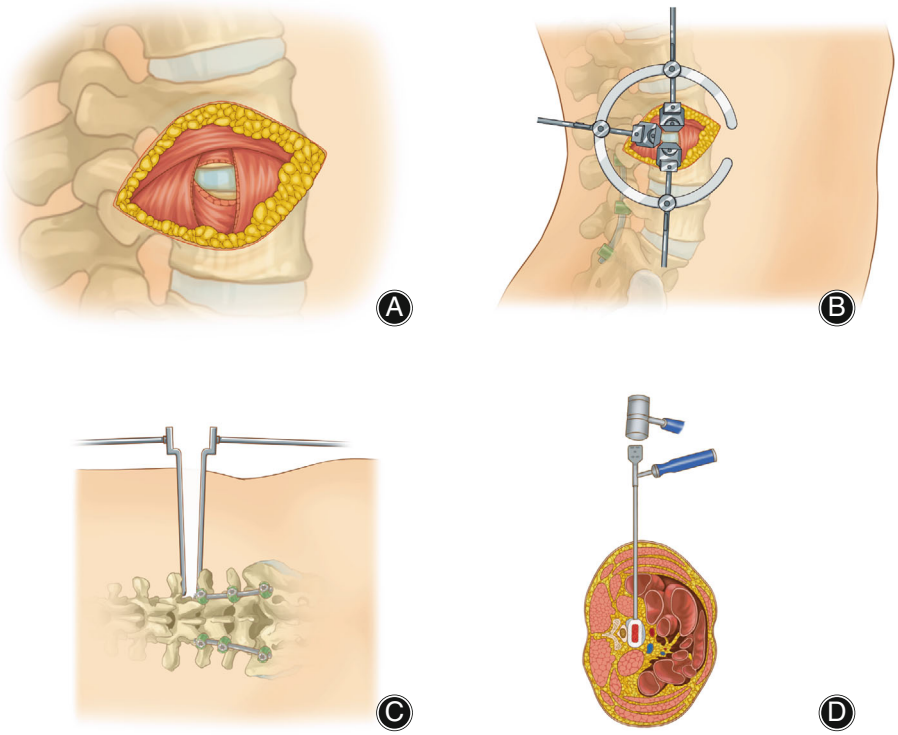

Fig. 1 Surgical procedure. (A) Surgical incision. (B, C) The installation of C-ring and retractors. The half-screw fixation screws were not utilized during this process. (D) The implantation of the cage. The cage was large enough to extend to the edge of the vertebra.

Clinical Outcomes

*Visual Analogue Scale (*VAS*)*
The visual analogue scale is a commonly used method to assess pain intensity. It is a 10 cm ruler with a score of 0 on one end indicating no pain and a score of 10 on the other end indicating the most intolerable pain. With this method, the patient is allowed to mark the corresponding position on the ruler, representing the degree of pain of oneself. 0 point signifies that the patient does not feel any pain. A score below 3 indicates mild pain; 4 to 6 indicates that the pain is more obvious; a scale of 7–10 indicates the pain is very intense to unbearable.

*Oswestry Disability Index (*ODI*)*
Oswestry Disability Index is a principal condition-specific outcome measure used in the management of spinal disorders, and to assess patient progress in routine clinical practice. The ODI score system includes 10 sections: pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sex life, social life, and traveling. For each section of six statements, the total score is 5. Intervening statements are scored according to rank. If more than one box is marked in each section, the highest score is counted. The score is calculated as follows: total scored out of total possible score $\times$ 100.0%–20% is considered mild dysfunction, 21%–40% indicates moderate dysfunction, 41%–60% implies severe dysfunction, and 61%–80% is considered a disability. A score of 81%–100% means that the patient is either long-term bedridden or exaggerating the impact of pain on their life.

The VAS scores of the back pain and leg pain and the ODI scores were obtained at the time before the operation, 2 weeks after the operation, 3 months after the operation, and at the last follow-up respectively. The change of each variable was defined as the difference between the last follow-up and preoperative values and was denoted as $\triangle$. The incidence of perioperative complications was also collected.

Radiological Parameter

Anteroposterior and lateral lumbar X-rays, lumbar CT, MRI, and femoral neck bone mineral density (BMD) were routinely performed preoperatively.

Lumbar Lordosis (LL)
Lumbar lordosis was defined as the angle between the upper endplate of L1 and the upper endplate of S1.

Segmental Lordosis (SL)
Segmental lordosis was defined as the angle between the lower endplate of the upper vertebral body and the upper endplate of the lower vertebral body in the diseased disc.

The Height of the Intervertebral Space (HIS)
Height of the intervertebral space was defined as the vertical distance from the midpoint of the lower endplate of the upper vertebra to the upper endplate of the lower vertebra.

The Height of the Intervertebral Foramen (HIF)
Height of the intervertebral foramen was defined as the shortest diameter between adjacent pedicles of the foramina.

The Cross-sectional Area (CSA) of the Vertebral Canal
Cross-sectional area of the vertebral canal was defined as the area where spinal stenosis was most severe at the diseased disc level.

Lumbar lordosis and segmental lordosis were measured on a standing lateral lumbar radiograph. Furthermore, CT and MRI were employed to observe intervertebral disc herniation and calcification. HIS, HIF, and the CSA of the vertebral canal were determined by MRI. BMD of the femoral neck was examined to evaluate osteoporosis. Anteroposterior and lateral lumbar X-rays and MRI were performed after surgery and at the last follow-up. The standing lumbar plain radiographs were used to evaluate the status of interbody fusion (fusion criteria: lack of transparency at the graft-host interface, graft bonding to the vertebral endplate, no graft migration, no settlement, and bridging trabeculae across the gap).[13] The change of each variable was defined as the difference between the last follow-up and preoperative values and was denoted as △.

Statistical Analysis
The SPSS 24.0 software (IBM, Armonk, NY, USA) was used for statistical analyses. The normal distribution data were expressed as mean ± SD, and the non-normal distribution data were expressed as the Median (IQR). The repeated-measures MANOVA was used to analyze the ODI score, LL, SL, HIS, HIF, and CSA of the vertebral canal. The Friedman *M* test was used to analyze the VAS score. The Spearman's test was used to analyze the association between clinical outcomes and radiographic parameters. Multivariate linear regression was used to analyze the influencing factors of low back pain. $P < 0.05$ indicated that the difference was statistically significant.

Results

Baseline Characteristics of Study Participants
A total of 46 lumber ASD patients who underwent the CLIF procedure between June 2018 and December 2019 were reviewed. Two patients were excluded because they underwent surgical procedures during the follow-up period, and one was further excluded because of trauma resulting in a lumbar fracture in the surgical area. Another six patients were lost to follow-up. Finally, 37 patients were included in the study. Among them, 13 were males, and 24 were females, with a mean age of 64.30 ± 5.92 years at the time of surgery. There were 22 cases of hypertension and 11 cases of diabetes. Among them, 23 lesions were located at the $L_{2/3}$ region and 14 at the $L_{3/4}$ region. The average follow-up time was 16.63 ± 4.24 months. The average time between the first operation and our surgical procedure was 5.06 ± 0.58 years. The median VAS score for back and leg pain was 7, while the ODI score was (67.48 ± 7.17) %. Moreover, the average *T* value of the femoral neck BMD was −(2.13 ± 0.46) (Table 1). All patients received strict and regular conservative treatment for at least 3 months before the surgical procedure.

TABLE 1 Demographic data of patients

Variables	Data
Number of patients	37
Sex	
Male	13
Female	24
Age	64.30 ± 5.92
BMD	−(2.13 ± 0.46)
Surgical level	
$L_{2/3}$	23
$L_{3/4}$	14
The time between the first surgery (year)	5.06 ± 0.58
Blood loss (ml)	40.37 ± 6.19
Operative time (min)	111.30 ± 10.80
Follow-up (months)	16.63 ± 4.24

Abbreviation: BMD, bone mineral density.

Intraoperative Results
The operation of the 37 patients in this group was successfully completed. The surgical time was 111.30 ± 10.80 min, and blood loss was 40.37 ± 6.19 mL. Thirty six patients got out of bed with a brace after 2 to 3 days following the operation, while one patient due to delayed healing of the surgical incision did not.

Clinical Outcomes

VAS_Back Score
The VAS_back score was 4 (3, 4), 1 (1, 2), 1 (0, 1) at 2 weeks after surgery, 3 months after surgery, and the last follow-up respectively. The differences were statistically significant compared with those before surgery ($P < 0.05$). The differences were statistically significant compared to 3 months after surgery and the last follow-up with 2 weeks after surgery ($P < 0.05$). The difference was not statistically significant compared between 3 months after surgery and the last follow-up ($P > 0.05$).

VAS_Leg Score
The VAS_leg score was 3 (3), 1 (1),1 (0, 1) at 2 weeks after surgery, 3 months after surgery, and the last follow-up respectively. The differences were statistically significant compared with those before surgery ($P < 0.05$). The differences were statistically significant compared to 3 months after surgery and the last follow-up with 2 weeks after surgery ($P < 0.05$). The difference was not statistically significant compared between 3 months after surgery and the last follow-up ($P > 0.05$).

ODI *Score*

The ODI score was (37.15 ± 7.11) %, (10.33 ± 4.15) %, and (7.07 ± 2.66) % at 2 weeks after surgery, 3 months after surgery, and the last follow-up respectively. The differences were statistically significant compared with those before surgery ($P < 0.05$). The differences were statistically significant compared to 3 months after surgery and the last follow-up with 2 weeks after surgery ($P < 0.05$). The difference was statistically significant compared between 3 months after surgery and the last follow-up ($P < 0.05$) (Table 2).

Radiological Parameters

The Height of the Intervertebral Space (HIS)

The HIS was (10.40 ± 0.73) mm, (9.50 ± 0.66) mm, and (9.44 ± 0.61) mm at 2 weeks after surgery, 3 months after surgery, and the last follow-up respectively. The differences were statistically significant compared with those before surgery ($P < 0.05$). The differences were statistically significant compared to 3 months after surgery and the last follow-up with 2 weeks after surgery ($P < 0.05$). But the difference was not statistically significant compared between 3 months after surgery and the last follow-up ($P > 0.05$).

The Height of the Intervertebral Foramen (HIF)

The HIF was (19.05 ± 2.06) mm, (17.40 ± 1.95) mm, and (17.30 ± 1.90) mm at 2 weeks after surgery, 3 months after surgery, and the last follow-up respectively. The differences were statistically significant compared with those before surgery ($P < 0.05$). The differences were statistically significant compared to 3 months after surgery and the last follow-up with 2 weeks after surgery ($P < 0.05$). But, the difference was not statistically significant compared between 3 months after surgery and the last follow-up ($P > 0.05$).

The Cross-sectional Area (CSA) of the Vertebral Canal

The CSA of vertebral canal was (74.12 ± 9.21) mm^2, (70.85 ± 8.99) mm^2, and (70.49 ± 8.95) mm^2 at 2 weeks after surgery, 3 months after surgery, and the last follow-up respectively. The differences were statistically significant compared with those before surgery ($P < 0.05$). But, the differences were not statistically significant compared between pairwise postoperative time points ($P > 0.05$).

Lumbar Lordosis (LL)

The LL was (45.48 ± 6.64)°, (45.11 ± 6.50)°, and (44.67 ± 6.38)° at 2 weeks after surgery, 3 months after surgery, and the last follow-up respectively. The differences were statistically significant compared with those before surgery ($P < 0.05$). But, the differences were not statistically significant compared between pairwise postoperative time points ($P > 0.05$).

Segmental Lordosis (SL)

The SL was (13.89 ± 3.46)°, (13.70 ± 3.40)°, and (13.44 ± 3.27)° at 2 weeks after surgery, 3 months after surgery, and the last follow-up respectively. The differences were statistically significant compared with those before surgery ($p < 0.05$). But, the differences were not statistically significant compared between pairwise postoperative time points ($P > 0.05$). (Table 3).

All patients achieved optimal interbody fusion according to the criteria for plain radiographs. A typical case was depicted in Fig, 2.

Correlation and Regression Analysis

To clarify the correlation between the improvement in clinical outcomes and radiological outcomes, the correlation analysis of the difference between these parameters were performed. As shown in Table 4, a positive correlation between △VAS_Back and △VAS_Leg was observed. On the other hand, △VAS_Leg was negatively correlated with △HIS, △HIF, and △CSA, respectively. Furthermore, HIS was positively correlated with △HIF and △CSA but negatively correlated with △SL. △HIF was positively correlated with △CSA but negatively correlated with △SL. △CSA was negatively correlated with △SL. △LL was positively correlated with △SL. There was no significant correlation between the remaining parameters. Interestingly, the multivariate linear regression analysis with △VAS_Back as the dependent variable showed that AGE, △LL, and △SL were significant risk

TABLE 2 Comparison of functional indexes at various time points before and after the operation

Time	Patients (*n*)	VAS_Back	VAS_Leg	ODI score (%)
Preoperative	37	7 (7, 8)	7 (6, 8)	67.48 ± 7.17
2 weeks after surgery	37	4 (3, 4)[a]	3 (3, 3)[a]	37.15 ± 7.11[a]
3 months after surgery	37	1 (1, 2)[a,b]	1 (1, 1)[a,b]	10.33 ± 4.15[a,b]
The last follow-up	37	1 (0, 1)[a,b]	1 (0, 1)[a,b]	7.07 ± 2.66[a,b,c]
Statistic	/	$Z = 93.775$	$Z = 91.763$	$F = 675.134$
P values	/	0.000	0.000	0.000

Notes: VAS scores are non-normally distributed data, expressed as medians, analyzed by the Friedman *M* test; ODI scores are normally distributed data, expressed as mean ± SD, analyzed by repeated-measures ANOVA.; Abbreviation: ODI, Oswestry Disability Index; VAS, Visual Analogue Scale.; [a] Indicates that the difference is statistically significant compared with preoperative.; [b] Indicates that the difference is statistically significant compared to 2 weeks after surgery.; [c] Indicates that the difference is statistically significant compared to 3 months after surgery.

TABLE 3 Comparison of imaging parameters at each time point before and after the operation

Time	Patients (*n*)	HIS (mm)	HIF (mm)	CSA (mm^2)	LL (°)	SL (°)
Preoperative	37	4.80 ± 0.73	12.95 ± 2.07	59.52 ± 9.22	37.22 ± 5.92	4.78 ± 1.99
2 weeks after surgery	37	10.40 ± 0.73[a]	19.05 ± 2.06[a]	74.12 ± 9.21[a]	45.48 ± 6.64[a]	13.89 ± 3.46[a]
3 months after surgery	37	9.50 ± 0.66[a,b]	17.40 ± 1.95[a,b]	70.85 ± 8.99[a]	45.11 ± 6.50[a]	13.70 ± 3.40[a]
The last follow-up	37	9.44 ± 0.61[a,b]	17.30 ± 1.90[a,b]	70.49 ± 8.95[a]	44.67 ± 6.38[a]	13.44 ± 3.27[a]
Statistic (*F*)	/	371.216	46.201	13.211	10.372	56.184
P values	/	0.000	0.000	0.000	0.000	0.000

Abbreviations: CSA, the cross-sectional area of vertebral canal; HIF, the height of the intervertebral foramen; HIS, the height of the intervertebral space; LL, lumbar lordosis; SL, segment lordosis.*Notes*: The normally distributed data expressed as mean ± SD and analyzed by repeated-measures ANOVA.; [a] Indicates that the difference is statistically significant compared with preoperative.; [b] Indicates that the difference is statistically significant compared to 2 weeks after surgery.

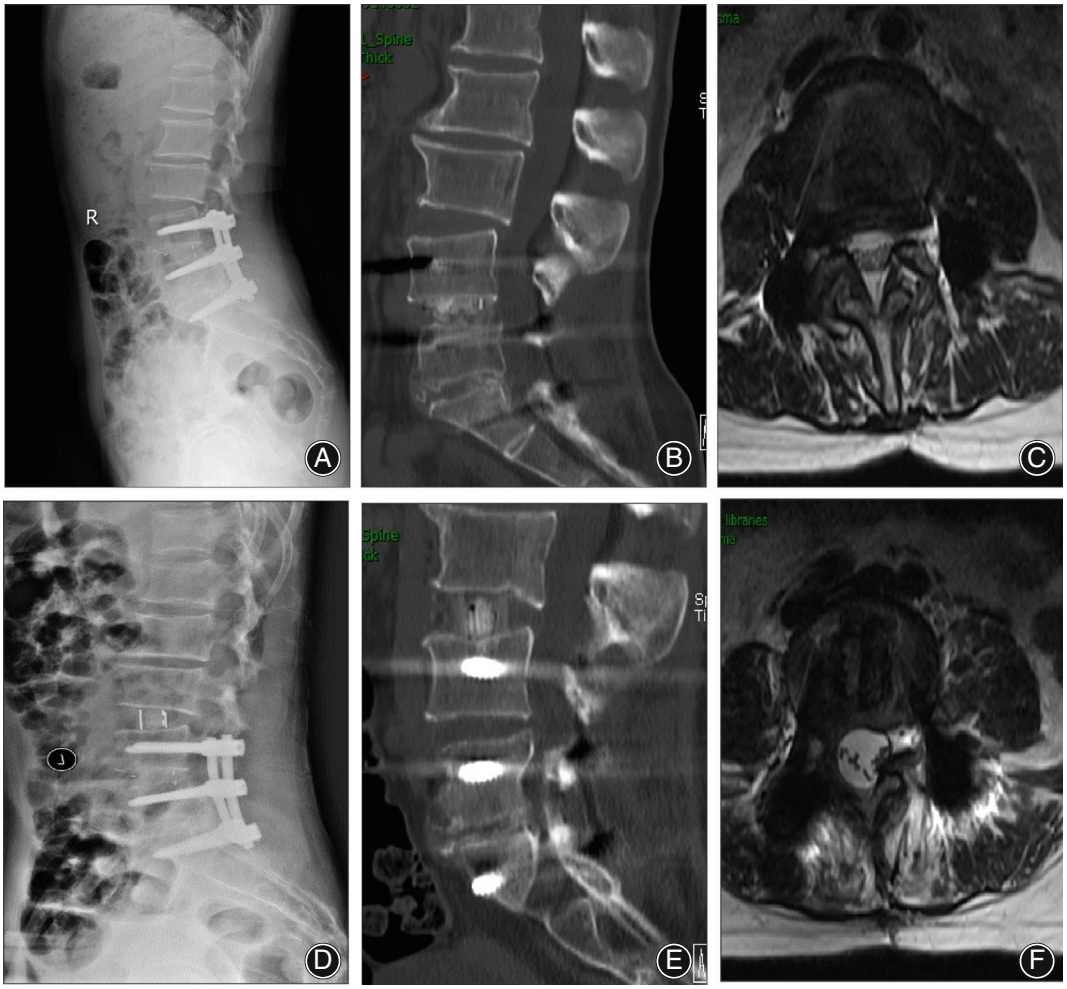

Fig. 2 The patient was a 57-year-old female. More than 5 years after lumbar fusion surgery, and who experienced pain and numbness in the back and lower extremities for half a year. (A-C) Preoperative lateral x-ray, CT, and MRI of the lumbar spine. (A) Preoperative lateral radiographs. It can be seen that lumbar lordosis (LL) decreased and $L_{3/4}$ SL became larger. Lumbar spondylolisthesis occurs at the $L_{3/4}$ level. (B) The same signs can be seen in preoperative CT of the lumbar spine. In addition, we can also observe that there is no calcification of the disc in the diseased segment. (C) Preoperative lumbar MRI can reveal the cross-sectional area of the vertebral canal becomes smaller. (D-F) Lateral x-ray, CT, and MRI of the lumbar spine after CLIF surgery was performed. (D) Postoperative lateral radiographs of the lumbar spine showed that both LL and SL of the diseased level returned to normal, and lumbar alignment was significantly improved. (E) The same signs can be seen in postoperative CT of the lumbar spine. (F) From postoperative MRI of the lumbar spine, it can be seen that the cross-sectional area of the vertebral canal increased.

TABLE 4 Correlation analysis between radiological parameters and clinical outcomes

	△VAS_Back	△VAS_Leg	△ODI	△HIS	△HIF	△CSA	△LL	△SL
△VAS_Back	1	0.397*	−0.35	−0.394	−0.361	−0.335	−0.119	0.102
		$P = 0.040$	$P = 0.861$	$P = 0.074$	$P = 0.064$	$P = 0.088$	$P = 0.556$	$P = 0.611$
△VAS_Leg		1	−0.256	−0.422*	−0.435*	−0.417*	0.168	0.214
			$P = 0.198$	$P = 0.028$	$P = 0.023$	$P = 0.031$	$P = 0.403$	$P = 0.238$
△ODI			1	0.066	0.066	0.063	−0.127	−0.205
				$P = 0.743$	$P = 0.742$	$P = 0.755$	$P = 0.529$	$P = 0.306$
△HIS				1	0.997**	0.981**	−0.291	−0.465*
					P <0.001	P <0.001	$P = 0.141$	$P = 0.015$
△HIF					1	0.986**	−0.305	−0.470*
						P <0.001	$P = 0.121$	$P = 0.013$
△CSA						1	−0.319	−0.479*
							$P = 0.105$	$P = 0.011$
△LL							1	0.836**
								P <0.001
△SL								1

Abbreviations: CSA, cross-sectional area; HIF, height of the intervertebral foramen; HIS, height of the intervertebral space; LL, lumbar lordosis; ODI, Oswestry Disability Index; SL, segmental lordosis; VAS, visual analogue scale.*Notes*: △ This represents the change between the last follow-up and pre-operation. The correlation was analyzed by Spearman's test.; * Indicates that $P < 0.05$.; ** Indicates that $P < 0.01$.

TABLE 5 Univariate analysis of each variable for △VAS_Back

Variables	Beta	Standardized beta	*t*	*P*-value	95% CI
Age	−0.104*	−0.432*	−2.347	0.032	(−0.197, −0.01)
Sex	−0.115	−0.038	−0.172	0.866	(−1.538, 1.307)
BMD	−0.336	−0.109	−0.568	0.578	(−1.589, 0.918)
△VAS_Leg	−0.098	0.086	0.441	0.665	(−0.567, 0.372)
△ODI	0.013	−0.062	−0.326	0.748	(−0.072, 0.099)
△HIS	−04.080	−0.861	−1.074	0.299	(−12.131, 3.971)
△HIF	3.733	1.29	1.68	0.112	(−0.978, 8.444)
△CSA	−0.068	−0.08	−0.306	0.764	(−0.538, 0.403)
△LL	0.839*	1.042*	2.538	0.022	(0.138, 1.540)
△SL	−0.744*	−1.08*	−2.582	0.02	(−1.356, −0.133)

Abbreviations: BMD, bone mineral density; CSA, cross-sectional area; HIF, height of the intervertebral foramen; HIS, height of the intervertebral space; LL, lumbar lordosis; ODI, Oswestry Disability Index; SL, segmental lordosis; VAS, Visual Analogue Scale.; Note: * Indicates that $P < 0.05$.

TABLE 6 Multivariate analysis of each variable for △VAS_Back

Variables	Beta	Standardized beta	*t*	*P* -value	95% CI
Age	−0.108*	−0.450*	−2.414	0.024	(−0.200, −0.015)
△LL	0.822*	1.021*	2.498	0.020	(0.141, 1.503)
△SL	−0.816*	−1.183**	−2.875	0.009	(−1.403, −0.229)

Abbreviations: LL, lumbar lordosis; SL, segmental lordosis; VAS, visual analogue scale.; Notes: * Indicates that $p < 0.05$.; ** Indicates that $p < 0.01$.

factors of △VAS_Back (Table 5). The parameters without statistical significance were removed, and the multiple linear regression was re-fitted (Table 6). The regression equation was as follows: △VAS_Back = 14.520- AGE × 0.450 +- △LL × 1.021 - △SL × 1.183.

Complications

There were no vascular and nerve-related complications during the operation. After the operation, surgical incisions in 36 cases healed by primary intention, and one patient developed delayed primary healing due to poor glycemic control.

Also, one case developed numbness in the front of the thigh, however, the symptoms resolved 3 months postoperatively. There were no complications such as bedsores, falling pneumonia, and deep venous thrombosis of the lower extremities. The typical caseses were shown in Fig 2 and Fig S1-3.

Discussion

Clinical and Radiological Results of CLIF Procedure

Herein, the patients' back and leg pain was significantly alleviated after CLIF surgery, and the ODI score was also significantly improved compared to the preoperative score. This indicates that the CLIF procedure can bring about significant nerve decompression and spinal stabilization in the management of lumber ASD. The radiological parameters showed that the HIS, HIF, and CSA of the vertebral canal were significantly better than preoperatively. Correlation analysis demonstrated that △VAS_Leg was negatively correlated with △HIS, △HIF, and △CSA of the vertebral canal, which could clarify the relationship between the improvement of radiological parameters and the alleviation of symptoms.

The Effects of CLIF Procedure on LL and SL of the Lumbar Spine

To further clarify the relationship between lumbar curvature and ASD, as well as the improvement of lumbar curvature by CLIF surgery, we compared LL and SL before and after surgery. The results showed that most patients did not achieve favorable LL and SL after the initial operation. With the improvement of SL and LL after this operation, patients' low back pain symptoms were significantly relieved. This demonstrates that LL and SL are closely related to the occurrence of ASD. The improvement of LL and SL can relieve patients' back pain, consistent with previous studies.[14–16] Interestingly, the multifactorial linear regression analysis found that LL is a protective factor for low back pain, but SL is a risk factor for low back pain. This may be relevant to stress concentration and overcompensation in adjacent segments; thus, further clinical trials and observations are required to clarify this finding. Theoretically, with the recovery of LL and SL, the probability of recurrence of ASD will be significantly reduced, which also calls for further investigations.

Whether Additional Fixation Is Required?

It is still controversial whether additional fixation is required after lumbar lateral fusion.[17,18] A systematic review revealed that stand-alone lateral lumbar interbody fusion could achieve reasonable interbody fusion rates, but rigorous surgical indications are required for the use of this procedure.[19] We believe that for patients with severe osteoporosis or intraoperative endplate injury additional fixation is required. In contrast, the stand-alone procedure can be performed first in patients with healthy bones, and additional posterior fixation can be determined according to the clinical manifestations and radiological parameters after surgery. All cases in this study were treated with a stand-alone procedure. During the follow-up period, cage sinking was identified in some cases. There were statistically significant differences in HIS between 2 weeks and 3 months after surgery, which implied that the peak of cage subsidence occurred from 2 weeks to 3 months after surgery, therefore appropriate lumbar protection was needed in this period. However, at the last follow-up, the HIS was significantly better than before surgery, and no worsening of symptoms occurred. There are also some studies showing no correlation between cage subsidence grade and postoperative radiculopathy, although cage subsidence may lead to the decrease of LL, which is a potential risk factor for ASD. However, there were no apparent clinical symptoms after more than 1 year.[20,21] This is consistent with our findings. Therefore, further follow-up is needed to determine whether additional fixation is needed.

Indications for CLIF Procedure

In addition, the CLIF procedure is not indicated for all types of lumbar ASDs. We hypothesize that the following conditions are not suitable for the CLIF procedure: (i) significant calcification of the intervertebral disc; (ii) the nucleus pulposus breaks through the posterior longitudinal ligament or floats in the spinal canal; (3) lumbar spondylolisthesis over degree II; and (iv) the lesion is too high or low, such as L1/2 or L5/S1. Therefore, an appropriate indication must be established when using the CLIF procedure to treat lumbar ASD.

Limitations

The present study has some limitations. First of all, this study has a small sample size and a relatively short follow-up period, therefore a more extended follow-up period and a larger sample size are imperative. Second, this is a retrospective study, and hence the level of evidence is not robust. Third, all patients were treated with stand-alone procedures, and some patients sustained cage subsidence after surgery, so further follow-up is required. In future studies, we will set posterior revision surgery as the control group for a prospective study, increase the sample size, extend the follow-up time, and further analyze the causes of cage subsidence.

Conclusion

In conclusion, CLIF surgery can achieve excellent clinical outcomes in the treatment of lumbar ASD. Due to its minimally invasive nature, the postoperative recovery is swift, and complications associated with being bedridden can be avoided. In addition, the radiological parameters of the lumbar spine were significantly improved, and satisfactory LL and SL could be restored. Therefore, the probability of recurrence of ASD will be theoretically reduced.

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Supporting Information

Additional Supporting Information may be found in the online version of this article on the publisher's web-site:

APPENDIX S1: Typical case S1.The patient was a 60-year-old female. (A) Preoperative lateral radiographs. (B) Preoperative CT of the lumbar spine. (C) Preoperative lumbar MRI. (D,E) Postoperative anteroposterior and lateral radiographs of the lumbar spine. (F) Postoperative MRI of the lumbar spine.

The patient was a 60-year-old female. (A) Preoperative lateral radiographs. (B) Preoperative CT of the lumbar spine. (C) Preoperative lumbar MRI. (D,E) Postoperativeanteroposterior and lateral radiographs of the lumbar spine. (F) Postoperative MRI of the lumbar spine.

APPENDIX S2: Typical case S2.The patient was a 55-year-old male. (A) Preoperative lateral radiographs. (B,C) Preoperative CT of the lumbar spine. (D) Postoperative lateral radiographs of the lumbar spine. (E,F) Postoperative MRI of the lumbar spine.

APPENDIX S3: Typical case S3.The patient was a 55-year-old female. (A) Preoperative lateral radiographs. (B) Preoperative CT of the lumbar spine. (C) Preoperative lumbar MRI. (D,E) Postoperative anteroposterior and lateral radiographs of the lumbar spine. (F) Postoperative MRI of the lumbar spine.

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