OPERATIVE TECHNIQUE

Oblique Lateral Endoscopic Decompression and Interbody Fusion for Severe Lumbar Spinal Stenosis: Technical Note and Preliminary Results

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Objective: Adequacy of decompression for oblique lateral interbody fusion (OLIF) is a real concern in patients with severe lumbar spinal stenosis (LSS). With this in mind, we combined OLIF with spinal endoscopic technique to achieve a solid fusion and an adequate decompression after one operation.

Methods: This is a technical note. The theoretical basis and operation process of this technique were introduced, and consecutive cases were retrospectively collected. Consecutive patients diagnosed with monosegmental severe LSS (L4/5) and underwent oblique lateral endoscopic decompression and interbody fusion (OLEDIF) from January 2018 to February 2020 were retrospectively collected. Clinical outcomes were assessed by claudication distance, Visual Analog Scale (VAS), and Oswestry Disability Index (ODI) scores. Secondary indicators included operation time, operative blood loss, and postoperative complications.

Results: Ten patients were selected for the OLEDIF procedure. They were five women and five men ranging in age from 49 to 75 years (mean age of 63.9 years) and in BMI from 25.4 to 30.2 kg/m^2 (mean BMI of 27.5 kg/m^2). The preoperative claudication distance was 160.00 ± 68.96 m (range 70–250 m), which was significantly extended on the 3-month and 1-year follow-up (1020.00 ± 407.70 m and 1040.00 ± 416.87 m, respectively). The preoperative VAS score of back pain and radiating leg pain was 5.50 ± 0.97 (range 4–7) and 6.40 ± 0.97 (range 5–8). The score on postoperative month 3 was 1.60 ± 0.52 (range 1–2) and 1.20 ± 0.79 (range 0–2), and the 1-year follow-up score was 1.90 ± 0.74 (range 1–3) and 1.60 ± 0.70 (range 1–3), respectively. The preoperative ODI was 72.23 ± 6.30 (range 64.4–82.2), the 3-month follow-up ODI was 31.12 ± 4.20 (range 24.4–35.6), and the 1-year follow-up ODI was 29.33 ± 5.92 (range 20.0–37.8). Compared with the transforaminal lumbar interbody fusion (TLIF) in the literature, the operation time was not prolonged (189.3 ± 32.5 min vs. 214.9 ± 60.0 min) but the amount of blood loss decreased significantly (113.3 ± 26.7 ml vs. 366.8 ± 298.2 ml). No complications were found except one case presented with dysesthesia of the left leg. Imaging results showed good fusion without cage subsidence during 1-year follow-up.

Conclusion: OLEDIF can achieve complete ventral decompression of the spinal canal and solid fusion of the lumbar spine at one time. It is an effective minimally invasive technique for the treatment of monosegmental severe LSS, which is promising and worthy of further clinical practice.

Key words: interbody fusion; lumbar spinal stenosis; oblique lateral approach; spinal endoscopy

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Introduction

In recent years, with the increasing emphasis on the importance of posterior ligament complex (PLC) and the complications of traditional posterior instrumentations, the lateral approach of lumbar surgery has gradually entered the vision of surgeons.[1,2] Many related minimally invasive surgical techniques such as oblique lateral interbody fusion (OLIF) have become popular in current management, especially for frail geriatric patients.[3,4] OLIF has good therapeutic effect on patients with Grade I/II spondylolisthesis and mild lumbar spinal stenosis (LSS).[5,6] Resection of two-thirds of the anterior disc and implantation of a larger cage compared with posterior lumbar interbody fusion (PLIF) can restore the intervertebral height, increase the intervertebral foramen volume, and straighten the flexed ligamentum flavum, thereby indirectly increasing the volume of spinal canal, which may be sufficient to improve mild stenosis and shape lumbar lordosis.[7–9] However, OLIF has its shortcomings that it cannot achieve complete decompression of the spinal canal. Due to the limitation of surgical site and channel, the removal of posterior disc tissue cannot be completed after entering the intervertebral space obliquely through the front of psoas, especially when the nucleus pulposus protrudes into the spinal canal. In addition, anatomical factors causing severe spinal stenosis such as hypertrophy and crumpled ligamentum flavum, facet joint hyperplasia, and osteophytes at the posterior edge of the vertebral body are difficult to remove, so complete decompression of spinal stenosis is not possible. Therefore, the current OLIF procedure may be considered as a technique to promote interbody fusion and restore lumbar lordosis with indirect decompression. Such techniques can achieve therapeutic effect in certain patients who do not have severe nerve compression.

Severe spinal stenosis symptoms occur when nerves are compressed on all sides, and there is no space for nerve roots or cauda equina to evade from compressive injury. The compensatory ability is lost and the neurological circulation is impaired, then neurodystrophy and demyelination occur successively. Theoretically, lumbar spine decompression in any direction can provide compensatory space for compressed nerve roots of LSS patients and may achieve satisfactory results.[10–13] Therefore, successful spinal canal decompression can be achieved by oblique lateral approach to remove the neuroventral compression structures. However, the deep and narrow working channel of OLIF makes it difficult to directly observe and remove the posterior nucleus pulposus or osteophyte. With the help of a spinal endoscope and semi-flexible endoscope forceps, the above tissues can be completely removed under direct vision to enlarge the volume of the central and lateral spinal canal. Heo *et al.* have attempted to use spinal endoscopy to assist the removal of herniated nucleus pulposus in OLIF surgery, however, there are few detailed technical introductions and quantitative assessments in their work.[14,15] This study will introduce the technique of oblique lateral endoscopic decompression and interbody fusion (OLEDIF) and corresponding case series in detail with the aims of (i) introducing the advantages and characteristics of this novel technique and (ii) reporting our preliminary results to evaluate its short-term efficacy and safety in the treatment of severe LSS.

Materials and Methods

Patient Information

The study was conducted in accordance with the Declaration of Helsinki and was approved by the National Rehabilitation Hospital's Medical Science Research Ethics Committee (IRB00006761-M2018008). We retrospectively reviewed consecutive patients who underwent OLEDIF surgery for the diagnosis of severe LSS between January 2018 and February 2020. The diagnosis of LSS was confirmed based on history, physical examination, and imaging findings.

The inclusion criteria were as follows: (i) the diagnosis of severe single-segment LSS with large herniated or prolapsed disc (exceeding 5 mm) located in the right lateral recess or central canal confirmed by lumbar magnetic resonance images (MRI); (ii) failed 6-week standard conservative treatment histories; (iii) underwent OLEDIF surgery; (iv) at least 1 year of follow-up. The exclusion criteria were as follows: (i) multilevel lumbar disc herniation; (ii) previous lumbar surgeries; (iii) abnormal aorta and inferior vena cava, or iliofemoral vein thrombosis; (iv) retroperitoneal fibrosis and adhesions.

Surgical Technique

Anesthesia and Exposure

The left lateral decubitus position and general anesthesia was chosen. The projection line through the center of the target disc and the midaxillary line were marked under radiography. The procedure is identical to the well-established lateral oblique operation.[5] In order to clearly expose the surgical field, a retractor with a light source can be used to identify the peritoneum, ureter, and lumbar sympathetic ganglia. The peritoneum was moved to the ventral side and the psoas muscle was retracted to the dorsal side. The genitofemoral nerve usually attaches to the anteromedial aspect of the psoas muscle and must be carefully protected. Moving along the anterior edge of the psoas muscle to its ventral side, the space between the psoas major and the aorta can be touched. After blunt separation of the space, the muscle and peritoneum were pulled apart with an S hook to expose the operating channel. After defining anatomical structures in the field of vision, the surgeon carefully separated the surgical field along the bone surface with "peanut." Bipolar coagulation was used to stop bleeding and then the disc space and annulus fibrosus (AF) were identified. Two Kasper screws were implanted on one side of the vertebrae for positioning and traction, with the probe inserted into the anterior third of the disc space. The correct position was confirmed by intraoperative fluoroscopy, followed by insertion of the guide

wire through the probe and subsequent insertion of the dilating cannulas as well as working cannula.

Decompression and Cage Implantation

An automatic retraction device (Grooved Dilator, Medtronic) was placed to expand a space parallel to the disc space to create an OLIF working channel. Generally, AF is cut along the endplate from the front to the back, otherwise the fiber at the uncut edge will block the channel like the "valve" as the devices enter and exit. After AF removal, discectomy and endplate chondrectomy can be performed, but attention should be paid to keeping the insertion direction parallel to the intervertebral space when the device is inserted deeply. After the nucleus pulposus was removed, the contralateral AF was released from back to front by gentle tapping or rotating of the Cobb detacher. A spinal endoscope with an operating channel and an irrigation channel was inserted along the working channel (Fig. 1). The posterior third of the disc and AF could be processed under direct vision with semi-flexible punches and forceps, and care was taken to prevent the nucleus pulposus from falling into the spinal canal. Tight adhesion between the PLL and AF is common, so adequate separation must be performed before directly grasping the AF. When dealing with ventral protrusions of the lateral recess and central canal, the direction of the endoscope should be flexibly adjusted, and angled devices such as bending forceps, nucleus pulposus forceps, and radiofrequency probes should be used in cooperation to decompress the spinal canal as thoroughly as possible (Fig. 2). In addition, it is recommended to use an angled burr to remove osteophytes in the posterior edge of the vertebral body. In this process, bone debris should be removed in time and epidural adipose tissues should be retained as much as possible. The radiofrequency probe can be used for hemostasis when necessary. The "straight leg raising test (SLR)" can be performed during the operation to observe the expansion of the dura mater and the movement of the nerve root under the endoscope to evaluate the immediate decompression effect directly (Fig. 3).

If residual disc tissues were found on the endplate under endoscope, endplate preparation should be repeated before cage placement. After decompression, the surgical area was irrigated with sterile saline and hemostasis was performed by bipolar electrocoagulation. The intervertebral space was moderately retracted and different test models were tried until sufficient segmental stability was obtained. An appropriate cage filled with autologous cancellous bone was implanted into the corresponding disc space. Once satisfactory position and size of the cage is confirmed by intraoperative fluoroscopy, bone grafting is performed in the space ahead of the cage. The incision was closed layer by layer without the need for a drainage tube.

Internal Fixation

Lumbar instability refers to the pathological movement caused by the failure to maintain a normal position relationship between the lumbar vertebrae under normal load. This can be inferred from preoperative imaging findings such as flexion and extension radiographs.[16] If the lumbar spine is stable, internal fixation may not be required; if there is segmental instability, unreduced spondylolisthesis or evident osteoporosis, internal fixation after decompression is recommended. After closing the wound, the patient was turned to the prone position and fixed with percutaneous pedicle screws. Appropriate compressive stresses can be applied between the ipsilateral screws to stabilize the local frame. Cortical bone trajectory screw (CBT) is recommended for patients with severe osteoporosis and massive trabecular bone loss. The position of the cage and screws should be

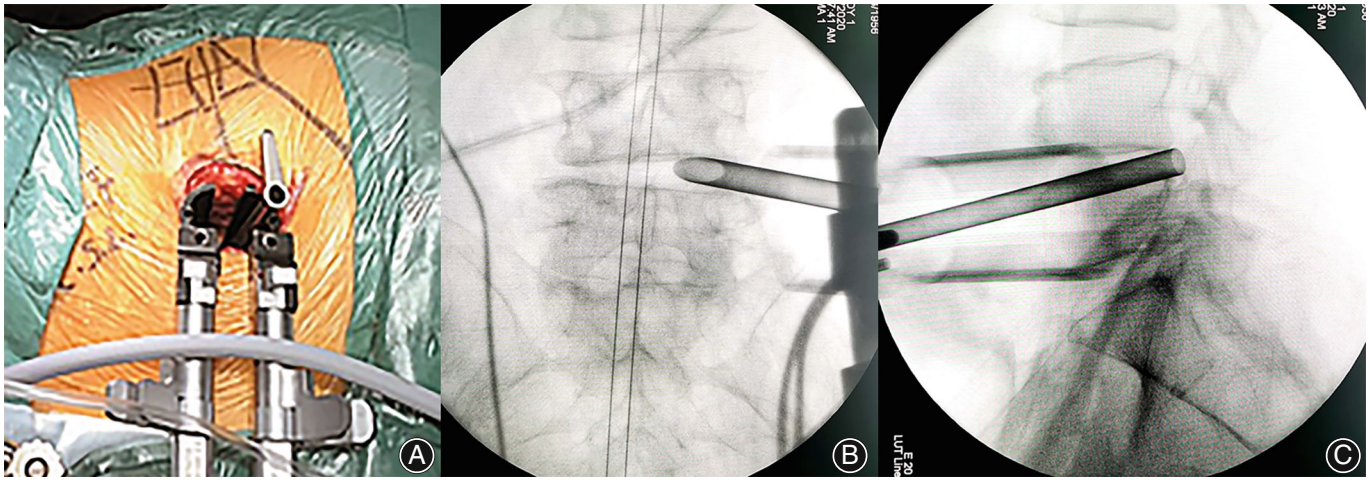

Fig. 1 Placement of spinal endoscope working cannula. (A) A photograph of the endoscopic working cannula in the OLIF field; (B and C) positions of the intervertebral retractor and the endoscopic working cannula confirmed by intraoperative anteroposterior and lateral fluoroscopy

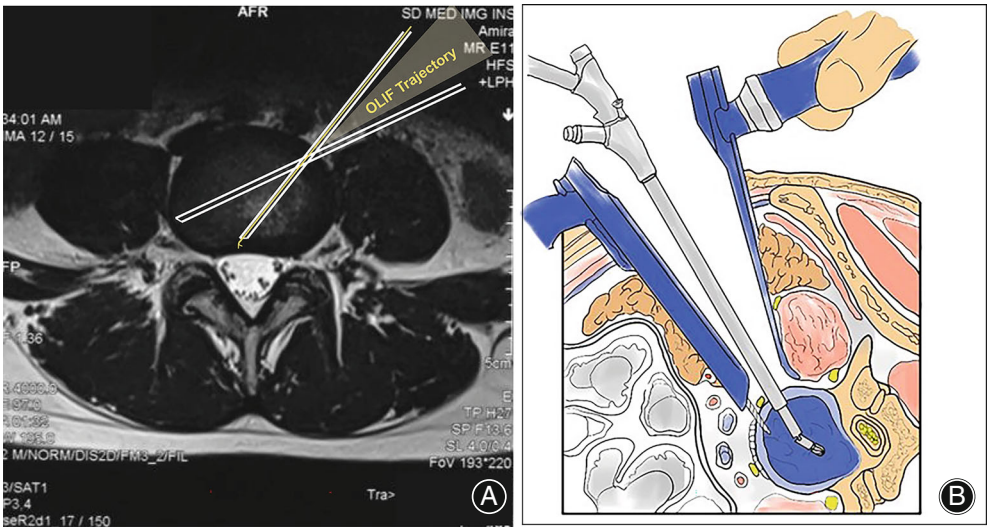

Fig. 2 The endoscopic decompression technique and range of OLEDIF. (A) Endoscopic working range of OLEDIF on MRI T2-weighted axial image; (B) schematic illustrating endoscopic lumbar spinal canal decompression *via* oblique lateral approach (hand drawing)

reassessed by fluoroscopy after internal fixation to minimize the occurrence of instrumentation failures.

Postoperative Course

Postoperative antibiotics and neurotrophic drugs were routinely given to minimize the occurrence of postoperative complications. For patients with neurological symptoms such as dysesthesia, dexamethasone and dehydrants were given for conservative treatment and excessive activities were limited. Patients should be instructed to perform ambulation and functional exercises of the low back muscles in the early postoperative period.

Clinical Assessment

Clinical outcomes were assessed by claudication distance, Visual Analog Scale (VAS), and Oswestry Disability Index (ODI) scores.

The claudication distance is the number of meters from the beginning of walking to being forced to stop due to lower limb pain and is usually described verbally by "1 km" or "100 steps." We converted all collected values into a unified unit at an average of 0.5 meters per step and recorded the distance change of each follow-up.

VAS is one of the commonly used pain scoring criteria, which divides the degree of pain from 0 to 10: 1–3 is mild pain, 4–6 is moderate pain, and 7–10 is severe pain.

ODI is widely used to evaluate the limitations of daily activities caused by spinal diseases and consists of 10 questions, including pain intensity, self-care, lifting, walking, sitting, standing, sleep, sex, social, and travel. The score range for each question was 0–5 points. Each question the patient answered is summarized and converted into a percentage score. The final score is divided into mild, moderate, relatively severe, severe, and extremely severe dysfunction according to the 0%–20%, 20%–40%, 40%–60%, 60%–80%, and 80%–100% intervals. The cage subsidence rate and fusion rate of the surgical segment were obtained by fluoroscopy at the 1-year follow-up to evaluate the long-term stability. In addition, the safety of surgical technique was assessed by operation time, intraoperative blood loss, and complication incidence. Follow-up points included 3 months and 1 year after surgery.

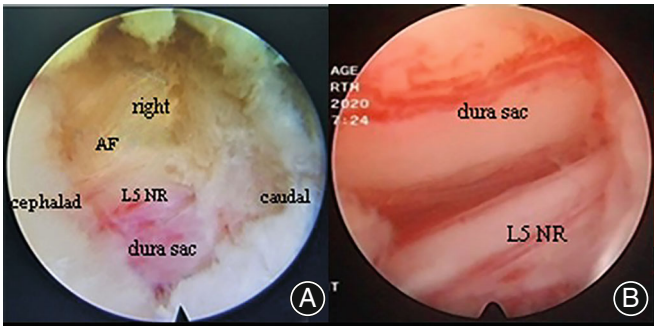

Fig. 3 Intraoperative endoscopic images. (A) An endoscopic surgical field and structure markers; (B) clearly exposed dural sac and nerve root after endoscopic decompression. AF, annulus fibrosus; NR, nerve root

Statistical Analysis

All data analysis was performed by SPSS version 22.0 (IBM, Armonk, NewYork, USA). Comparisons of claudication distance and functional scores at different periods in the same group were performed using paired t-tests. Differences between two groups were analyzed using Student's *t*-test. $p < 0.05$ indicated a statistically significant difference.

Results

General Results

Ten patients diagnosed with severe ventral LSS (L4/5) underwent OLEDIF between January 2018 and February 2020.

They were five women and five men ranging in age from 49 to 75 years (mean age of 63.9 years) and in BMI from 25.4 to 30.2 kg/m^2 (mean BMI of 27.5 kg/m^2).

All patients suffered from low back pain with radiating pain in the lower extremities, and intermittent claudication occurred after walking distance <300 m. Superficial sensory deficits can be found on the lateral aspect of one or both calves of six patients. The results of straight leg raising test were positive in four patients. The lower limb muscle strength was normal except for left extensor hallucis longus (EHL) strength in three patients and right EHL strength in two patients, which was declining to Grade 4/5.

All patients underwent OLEDIF surgery successfully after excluding surgical contraindications. The rehabilitation process was satisfactory, and all patients were discharged within 3 days of surgery (Table 1).

Intraoperative Findings

In terms of surgery, the mean operation time was 189.3 min and the amount of blood loss was 113.3 ml. Compared with the TLIF results in the literature, the operation time was not prolonged (189.3 ± 32.5 min *vs* 214.9 ± 60.0 min, $p > 0.05$) but the blood loss amount decreased significantly (113.3 ± 26.7 ml *vs* 366.8 ± 298.2 ml, $p < 0.05$).[17] Posterior internal fixation was performed in eight patients, of which two patients selected CBT for osteoporosis, and the remaining six patients underwent percutaneous pedicle screw implantation (Table 1).

Clinical Outcomes

The preoperative claudication distance was 160.00 ± 68.96 m (range 70–250 m), which was significantly extended on the 3-month and 1-year follow-up (1020.00 ± 407.70 m and 1040.00 ± 416.87 m, respectively) ($p < 0.001$, $p < 0.001$). The preoperative VAS score of back pain was 5.50 ± 0.97 (range 4–7), the score on postoperative month 3 was 1.60 ± 0.52 (range 1–2), and the 1-year follow-up score was 1.90 ± 0.74 (range 1–3). The preoperative VAS score of radiating leg pain was 6.40 ± 0.97 (range 5–8), the score on postoperative month 3 was 1.20 ± 0.79 (range 0–2), and the 1-year follow-up score was 1.60 ± 0.70 (range 1–3). The preoperative ODI was 72.23 ± 6.30 (range 64.4–82.2), the 3-month follow-up ODI was 31.12 ± 4.20 (range 24.4–35.6), and the 1-year follow-up ODI was 29.33 ± 5.92 (range 20.0–37.8). Statistically, there were significant differences in VAS and ODI scores before and after surgery ($p < 0.001$, $p < 0.001$, $p < 0.001$); there was no significant difference in the scores between the 3-month and 1-year follow-up ($p = 0.34$, $p = 0.59$, $p = 0.12$), although the related symptoms were slightly aggravated at 1 year after surgery. The decreased EHL muscle strength in five cases gradually recovered to Grade 5/5 within a month after surgery (Table 2).

Complications

As for complications, one patient had postoperative dysesthesia in front of her left thigh, which gradually relieved after intravenous drip of dexamethasone and dehydrants for 2 weeks. No infection, ureteral injury, vascular injury, or sympathetic nerve chain injury was reported. Imaging results showed that no cage subsidence occurred during the 1-year follow-up, even in two osteoporotic cases. The responsible segments of all cases achieved good fusion. Preoperative and postoperative lumbar MR images of one patient are shown in Fig. 4.

Discussion

Preliminary Outcome

Despite relatively few cases, 10 patients showed promising results at 3 months and 1 year after OLEDIF. All patients showed significant relief of low back pain and lower limb radiation pain; their walking distances were also significantly extended. The slight decrease in therapeutic effect 1 year after surgery may be related to recurrence, adjacent segment disease, or mental changes, which need further observation and examination. Postoperative imaging results showed that the decompression of responsible segment was sufficient and the instrumentations were all in appropriate position. No

TABLE 1 Basic characteristics and operative data of 10 patients who underwent OLEDIF

Patient ID	Gender	Age (years)	BMI (kg/m^2)	Operative Level	OPT (min)	BL (ml)	Internal Fixation
1	F	49	28.2	L4/5	158	83	—
2	F	75	27.9	L4/5	217	155	CBT
3	M	59	29.4	L4/5	143	97	PS
4	F	66	27.5	L4/5	202	105	PS
5	M	67	26.3	L4/5	187	95	PS
6	F	72	30.2	L4/5	225	130	CBT
7	F	52	25.4	L4/5	175	120	—
8	M	70	26.7	L4/5	238	147	PS
9	M	68	26.0	L4/5	150	75	PS
10	M	61	27.7	L4/5	198	126	PS

Abbreviations: F, female; M, male; BMI, body mass index; OPT, operation time; BL, blood loss; CBT, cortical bone trajectory; PS, pedicle screw.

TABLE 2 The major indicators of clinical outcomes of 10 patients who underwent OLEDIF

Patient ID	Claudication distance (meters)			VAS (back pain)			VAS (radiating leg pain)			ODI (%)			Imaging results	Complications (*n*)
	Preoperative	3-month follow-up	1-year follow-up	Preoperative	3-month follow-up	1-year follow-up	Preoperative	3-month follow-up	1-year follow-up	Preoperative	3-month follow-up	1-year follow-up	1-year follow-up	
1	100	800	800	6	1	1	6	2	2	68.9	28.9	26.7	Well-fused	0
2	200	900	1000	5	2	2	7	1	1	77.8	35.6	33.3	Well-fused	0
3	250	2000	2000	7	1	0	5	0	0	64.4	26.7	20.0	Well-fused	0
4	150	1000	1100	6	1	2	7	1	1	73.3	33.3	33.3	Well-fused	0
5	200	1400	1500	5	2	0	6	1	0	66.7	24.4	22.2	Well-fused	0
6	80	800	700	5	2	2	8	2	3	77.8	31.1	35.6	Well-fused	1: dysesthesia
7	200	1000	900	5	2	1	6	1	2	66.7	33.3	28.9	Well-fused	0
8	250	700	700	4	1	2	7	2	2	82.2	35.6	37.8	Well-fused	0
9	100	1000	1000	5	2	1	5	0	0	66.7	26.7	24.4	Well-fused	0
10	70	600	700	7	2	2	7	2	2	77.8	35.6	31.1	Well-fused	0

Abbreviations: VAS, Visual Analog Scale; ODI, Oswestry Disability Index.

cage subsidence or displacement was observed. Compared with TLIF or PLIF, the procedure is more conducive to patients due to less invasion and intraoperative blood loss.[17] Although both anterior lumbar interbody fusion (ALIF) and direct lateral interbody fusion (DLIF) can achieve interbody fusion without damaging the back muscles and ligaments, the transabdominal approach is a huge challenge for most orthopaedists. For example, DLIF *via* psoas approach has a high complication rate of muscle weakness, lumbar plexus and genitofemoral nerve injury.[18,19] To date, only one complication has been identified in our review of 10 cases. One patient presented with dysesthesia of the left leg that resolved within 2 weeks after surgery, which may be associated with minor injury of the lumbar plexus or psoas traction irritation. Long-term effects can only be carefully predicted.

Limitations of the Original OLIF

Compared with PLIF and TLIF, OLIF can significantly reduce the damage to the low back muscles and PLC even if posterior fixation is frequently required. An intact posterior structure is essential for the recovery of back muscle strength and the reduction of complication incidence in patients, especially adjacent segment degeneration and iatrogenic spondylolisthesis.[1,20] Moreover, reduced surgical trauma and bleeding from minimally invasive OLIF is beneficial to the enhanced recovery of LSS patients.[21] In terms of efficacy, the large cage used in OLIF can improve the fusion rate, restore the intervertebral height, reduce the wrinkles of the ligamentum flavum, and indirectly increase the volume of spinal canal.[7] However, the extent to which OLIF can increase spinal canal volume remains controversial, which is essentially equivalent to the debate on the value of ligamentotaxis alone in the management of spinal stenosis.[22] Several clinical studies have shown that it seems hard to achieve satisfactory nerve decompression for the stenosis of central canal and lateral recess caused by huge disc herniation.[23] In some cases, posterior decompression surgery must be added after OLIF to ensure complete nerve release, and is ultimately far away from the original intention of minimally invasive treatment.[5]

Advantages of the OLEDIF

In this case, we propose a novel concept of OLIF assisted by spinal endoscopy—OLEDIF—which can achieve adequate nerve decompression under direct vision and minimally invasive fusion at one time. The working cannula of spinal endoscope generally has a diameter of 7 mm, which can freely enter into the OLIF operative field. The field of view at the lens end is usually 30°–60°. With the aid of an external light source and a high-definition imaging system, the posterior AF, nucleus pulposus, and osteophytes can be clearly observed. The use of semi-flexible or angled removal tools for visual decompression can compensate for the anatomical defects of original OLIF and achieve efficient resolution of severe LSS. Since OLIF is performed with the patient in the left lateral decubitus position, the application of spinal

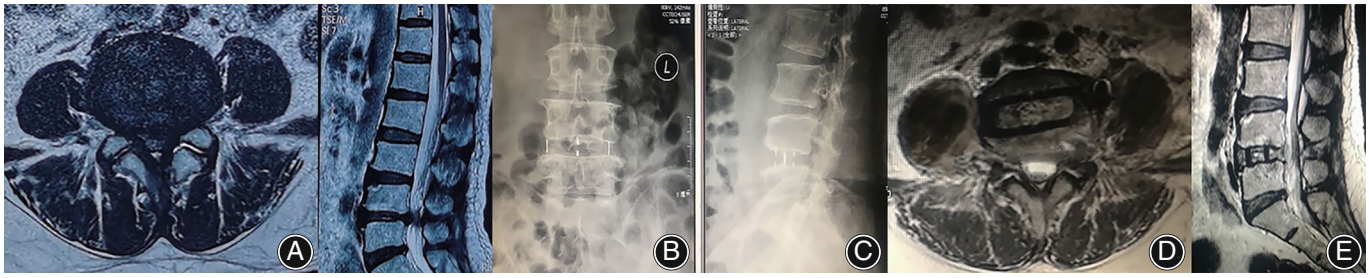

Fig. 4 Case No. 1, female, 65 years old. (A and B) Preoperative MR T2-weighted images showed obvious L4/5 disc herniation and spinal stenosis; (C and D) anterior–posterior and lateral fluoroscopy after OLEDIF showed good cage position and normal lumbar sagittal alignment; (E) postoperative MR T2-weighted images showed good spinal canal decompression and dural sac expansion

endoscopy makes it possible to remove the herniated nucleus pulposus of the right lateral recess and central canal. The huge ventral protrusion of the spinal canal with dubious indirect decompression effect can be cleaned by direct decompression under endoscope.

Neuroventral Decompression

After decades of clinical practice, the efficacy of anterior decompression has been well confirmed in cervical and thoracic spine surgery.[24,25] In the lumbar spine, timely decompression of the cauda equina and spinal nerves in any direction may achieve satisfactory results.[11–13] In cases of thoracolumbar burst fractures, the anterior approach has been reported to be as effective as the posterior approach when the spinal cord is compressed.[26] According to the "arch string theory" of lumbosacral plexus, by removing AF and PLL, the attachment ligament of the dura mater (dentate ligament) and spinal nerve can also be freed, thereby reducing tension and achieving ideal decompression.[27] Therefore, neuroventral decompression of the lumbar spine has high application value.

Surgical Precautions

Posterior nucleus pulposus and AF are generally not involved in original OLIF, but in OLEDIF these structures are removed in order to complete full decompression, which may make the intervertebral space and spinal canal directly connected. To prevent the implanted bone grains from entering the spinal canal, the cage should be placed first and then the autografts should be implanted in front of the device.[28] Consideration should also be given to how to prevent the cage from falling into the spinal canal. As we know, first of all, an appropriately sized cage should be selected, which is quite stable in the intervertebral space. Secondly, additional posterior instrumentations with compressive force can further prevent the cage migration. In addition, normal lumbar lordosis (LL) plays a key role in maintaining lumbar stability and satisfactory clinical outcomes in the long run. The large cage of OLIF is advantageous for remodeling the lower lumbar arc, but care should also be taken to refer to lordosis of adjacent segments, normal LL (LL = pelvic incidence $\pm 9°$), and Roussouly's sagittal alignment classification to avoid excessive distraction of the disc space.[29,30]

Internal Fixation

Whether pedicle or cortical screw fixation is performed after decompression and cage implantation depends on lumbar stability and bone mineral density (BMD). Since the PLC, facet joints and paravertebral muscles are intact, no additional posterior fixation is required if segmental instability is significantly improved after anterior column reconstruction by OLEDIF. However, additional posterior fixation is recommended if there is Grade II or above spondylolisthesis before operation, or if the reduction of spondylolisthesis is not ideal, or if the segmental instability after OLEDIF still exists.[31,32] Posterior fixation may help improve fusion rate and reduce the risk of cage displacement or subsidence. Although many studies have shown that posterior pedicle fixation may increase the incidence of complications such as adjacent segmental diseases, high-quality evidence is still insufficient.[32–34]

Limitations

The current study has certain limitations. First, this study was a single-center study with relatively small sample size and relatively short follow-up period. Longer follow-up period and more cases are required to evaluate the exact efficacy of OLEDIF in patients with severe LSS. Multi-center research is also essential to improve the richness and credibility of clinical results. Second, this work mainly reports surgical techniques and case series. The strength of OLEDIF need to be further demonstrated in comparative studies with higher evidence levels.

Conclusion

OLEDIF can achieve complete ventral decompression of the spinal canal and solid fusion of the lumbar spine at one time. The use of endoscope lens and semi-flexible tools for decompression under direct vision can compensate for the anatomical defects of original OLIF and makes it possible to remove the herniated nucleus pulposus of the central canal and right lateral recess. This technique combines the advantages of

endoscopic procedure and OLIF, which allows precise decompression and restoration of segmental lumbar lordosis, and is undoubtedly an effective minimally invasive approach for the treatment of severe LSS. From our limited cases, this technique is promising and warrants further clinical practice and long-term follow-up.

Ethics Approval and Consent to Participate

All procedures performed in the study involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments. The study was approved by the National Rehabilitation Hospital's Medical Science Research Ethics Committee. The patients have consented to participate in the study.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by FJ and CD. The draft of this paper was written by FJ. The final version was prepared by XD, YL, and XL.

Conflicts of Interest

The authors declare no conflict of interest. No benefits in any form have been, or will be, received from a commercial party related directly or indirectly to the subject of this manuscript.

Data Availability Statement

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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