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Full-endoscopic posterior lumbar interbody fusion for the treatment of lumbar degenerative diseases: a technical note with 2-year follow-up

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Abstract

Introduction The spinal endoscopic technique has been extensively documented in decompression procedures for treating lumbar degenerative diseases. However, there is limited literature on the spinal endoscopic in lumbar fusion techniques. This study evaluates the outcomes and safety of full-endoscopic posterior lumbar interbody fusion (Endo-PLIF) for the treatment of lumbar degenerative diseases.

Methods A retrospective case series was conducted at Beijing Chaoyang Hospital, Capital Medical University, involving 43 patients who underwent Endo-PLIF between February 2020 and March 2021, with a minimum follow-up period of two years. Clinical outcomes were evaluated using the Visual Analog Scale (VAS), Oswestry Disability Index (ODI), and modified MacNab criteria. VAS and ODI scores were analyzed using one-way analysis of variance (ANOVA) at preoperative, 3-month, 12-month, 24-month, and final follow-up time points. Paired t-tests were employed to compare imaging parameters, including lumbar lordosis, disc height, segmental lordosis, and foraminal area, between the preoperative and final follow-up assessments.

Results This study included 43 consecutive patients with a mean age of 60.7 years and an average symptom duration of 4.6 years. All surgical procedures were successfully completed, with a mean operation duration of 233.8 ± 38.6 min. Mean VAS and ODI scores showed significant improvements postoperatively, decreasing from 7.05 ± 3.05, 7.44 ± 2.95, and 67.52 ± 9.31 points preoperatively to 1.22 ± 0.54, 1.50 ± 0.42, and 20.42 ± 3.57 at the latest follow-up ($p < 0.001$). Disc height ($p = 0.012$) and foraminal area ($p = 0.013$) increased significantly. MacNab evaluation indicated 90.6% of patients had good to excellent outcomes. Three patients experienced symptomatic nerve root irritation.

Conclusion Endo-PLIF is safe and effective in the treatment of patients with lumbar degenerative disease in early follow-up. However, further extensive, long-term, multicenter studies are necessary to validate these findings.

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Keywords Clinical outcome, Disc herniation, Lumbar degenerative diseases, Microsurgery, Posterior lumbar interbody fusion

Introduction

Lumbar degenerative diseases are a primary cause of chronic low back pain in the aging global population [1], classified under ICD code M48.903. Common lumbar degenerative diseases encompass discogenic low back pain, lumbar disc herniation, lumbar spinal stenosis, and lumbar spondylolisthesis [2–4]. These conditions pose a significant burden on the elderly population, often leading to disability. In the early stages, conservative management is typically prioritized, encompassing interventions such as pain management, bed rest, lumbar and back muscle strengthening exercises, and neurotrophic therapies. Surgical intervention usually becomes necessary when conservative fail to yield satisfactory outcomes. The conventional open approach for decompression typically achieves comprehensive decompression of the cauda equina and nerve roots [5]. However, it is associated with drawbacks such as significant tissue trauma, blood loss, and prolonged recovery periods [6].

Spinal endoscopic technique offers several advantages over traditional open surgery, including reduced blood loss, minimized tissue damage, and faster recovery times [7–9]. While the technique has been extensively documented for decompression procedures in the treatment of lumbar degenerative diseases [10–12], there is limited literature on its application in lumbar fusion procedures. Full-endoscopic posterior lumbar interbody fusion (Endo-PLIF) is an emerging minimally invasive fusion technique that involves posterolateral resection of the inferior articular process and lamina to achieve decompression and bone graft fusion, distinguishing the trans-Kambin's triangle pathway. Endo-PLIF can simulate the surgical approach of open surgery while offering the advantage of an enhanced field of view [13]. Notably, a significant advantage of Endo-PLIF is its capacity for direct visualization of the endplates, facilitating optimal preparation and potentially improving fusion outcomes. Therefore, this study aimed to evaluate the outcomes and safety of Endo-PLIF for the treatment of lumbar degenerative diseases.

A retrospective study with a minimum 2-year follow-up was conducted. Our research concentrated on a case series involving patients with lumbar degenerative diseases who exhibited persistent low back pain despite conservative management. Endo-PLIF procedures were performed under general anesthesia, followed by pain relief evaluations and imaging data analysis.

Methods

Patient population

Medical records were reviewed to identify 43 patients with lumbar degenerative diseases who underwent Endo-PLIF in our orthopedics department between February 2020 and March 2021. All patients had comprehensive preoperative imaging, including X-ray, computed tomography (CT), and magnetic resonance imaging (MRI), along with complete follow-up records, and no previous history of lumbar surgery. The study procedures received approval from the ethics committee of Beijing Chaoyang Hospital, Capital Medical University (Registration number: 2022-KE-645).

Two senior attending physicians were involved in case collection. Inclusion criteria: (1) single-level lumbar degenerative diseases; (2) low back pain with or without associated symptoms that persisted despite non-surgical treatment for over 6 months; (3) patients who underwent follow-up assessments with X-ray, CT, and MRI. Exclusion criteria: (1) multilevel LDD involving more than two levels; (2) lumbar degenerative diseases accompanied by kyphoscoliosis; (3) pathological conditions such as spinal infection or tumor; (4) clinical signs and symptoms inconsistent with imaging findings; (5) cases of fresh spinal trauma and fractures.

Operative technique

Special instruments for the Endo-PLIF were designed and constructed (Fig. 1A, B). All operations were performed with patients in the prone position under general anesthesia. (1) Incision design. Under the guidance of a C-arm, 4 pedicle screw incisions and 1 endoscopic incision are marked. The endoscopic incision was made on the side with severe symptoms, and the incision was located at the midpoint of the line connecting the upper and lower pedicles. Typically, one of the pedicle incisions was extended, sharing it as the endoscopic incision. Then, two percutaneous pedicle screws were placed on the non-decompression side, along with a rod for pulling and lifting. On the decompression side, the guide wire was indwelled without the placement of the pedicle screw. The remaining two pedicles would be implanted after the subsequent decompression procedure. (2) Decompression. This surgical procedure achieves decompression through the posterolateral resection of the inferior articular process and lamina, rather than the trans-Kambin's triangle pathway. In the procedure, a first-level dilator was inserted through the incision onto the vertebral plate surface, gently separating the soft tissue attachment points between the upper and lower vertebral plates.

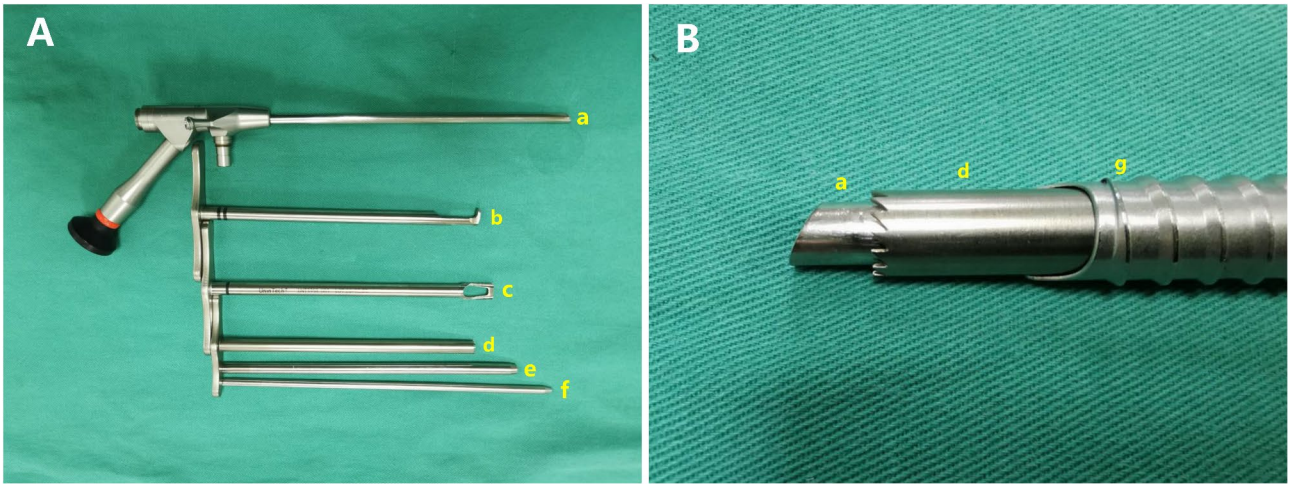

Fig. 1 Endoscopic system **(A**, **B)**. Spinal Endoscope (**a**), endplate curette (**b**), endplate shaver (**c**), trephine (**d**), dilation cannula (**e**), guide rod (**f**), cannula (**g**)

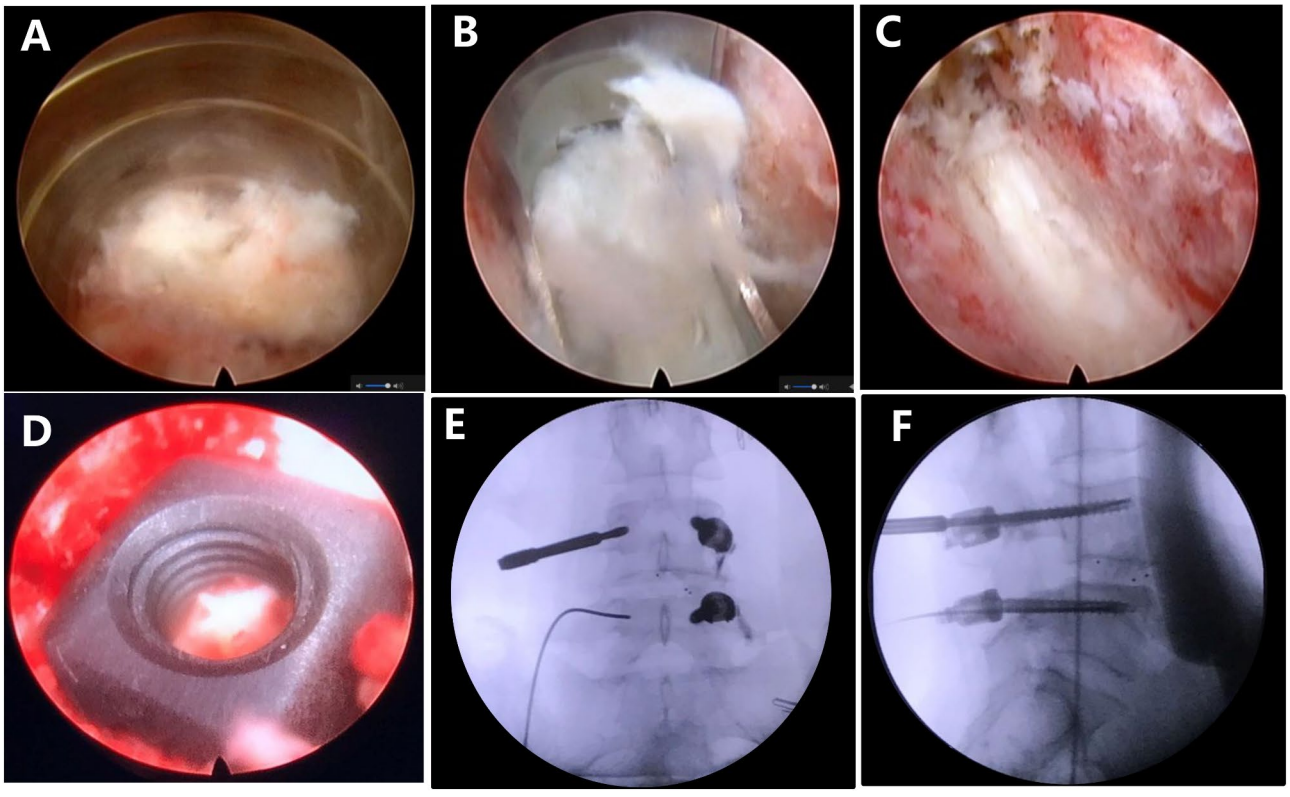

Fig. 2 The schematic diagram of the procedure. (**A**) Application of burrs to address bone tissue. (**B**) Utilization of a curette for the cartilage endplate management. (**C**) Visualization of the vertebral endplate post-processing. (**D**) Visualization of the status of cage implantation. (**E-F**) Anteroposterior and lateral X-rays demonstrating minimally invasive pedicle nail insertion

Subsequently, expandable tubes were gradually introduced to create a working channel and accommodate a spinal endoscope system. The procedure involved using a burr to excise the inferior articular process and a portion of the vertebral plate, exposing the upper limit of the ligamentum flavum. Radiofrequency hemostasis was then applied to expose the lateral edge of the ligamentum flavum and the tip of the superior articular process. Subsequently, a burr was used to remove part of the superior articular process, revealing the intervertebral disc and the space between the ligamentum flavum (Fig. 2A). This step also involved widening the ipsilateral neural foramen and lateral recess. We typically utilize the "over-the-top" technique for contralateral decompression, where

the working channel passes between the lamina and the dura mater, with careful attention to protecting the dura mater. For central decompression, we shift the working channel medially, which both exposes the surgical field and protects the nerve root and dural sac. (3) Fusion. A curette was used to prepare the intervertebral space until the cartilage endplate was completely removed and the bony endplate was fully exposed for optimal fusion (Fig. 2B-C). We restored lordosis through the compression of the pedicle screws. The local bone obtained from the prior laminectomy and facetectomy was inserted into the intervertebral space, and a cage was placed into the disc space through the fusion channel (16 mm in diameter) (Fig. 2D). Since the cage placement procedure was non-visual, the position of the cage was confirmed using C-arm imaging. Endoscopic examination ensures nerve root relaxation and checks for any residual nucleus pulposus tissue or active bleeding. Subsequently, the endoscope and fusion channel were removed. Bilateral percutaneous pedicle screws of appropriate length were placed and secured in the upper and lower vertebrae (Fig. 2E-F), followed by traction and reduction. The connecting rod was then installed, and fluoroscopy used again to verify the position of the internal fixation. Finally, the surgical incision was closed in layers.

Clinical evaluation

We gathered baseline patient data, including age, gender, segment of intervertebral foramen stenosis, presence or absence spondylolisthesis, surgical duration, blood loss, postoperative bed rest duration, hospital stay, follow-up period, and fusion rate. Preoperative and postoperative clinical assessments were conducted at multiple time points, including baseline and at 3, 12, and 24 months, as well as during the last follow-up visit. Pain severity was evaluated using the visual analog scale (VAS), ranging from 0 (no pain) to 10 (maximum, unimaginable pain), for both back (VAS-back) and leg (VAS-leg) pain. Functional status was assessed using the Oswestry Disability Index (ODI).

Radiologic measurements

Lumbar lordosis, segmental lordosis angle, and disc height were assessed using standard lateral X-rays of the lumbar spine obtained with the patient in the standing position. Disc height is defined as the average of the intervertebral spaces at the anterior and posterior margins of the vertebral body. Lumbar lordosis is defined as the angle between the superior surfaces of the L1 and S1 vertebral bodies, while segmental lordosis is defined as the angle between the superior surfaces of the vertebral bodies of the operated segments. Additionally, decompression efficacy was evaluated by assessing the foramen area on sagittal reconstructions obtained from lumbar magnetic resonance imaging scans. For accuracy, three measurements were taken and averaged.

Fusion assessment

Lumbar CT scans, including sagittal and coronal images of the bone reconstruction, were obtained and utilized to evaluate fusion at the last follow-up. Interbody fusion success was assessed and classified based on the Brantigan, Steffee, and Fraser (BSF) criteria [14]. BSF-1: Radiographic pseudarthrosis (nonfusion) is characterized by construct collapse, loss of disc height, vertebral slip, broken screws, carbon cage displacement, significant bone graft resorption, or lucency around the graft or cage. BSF-2: Radiographic locked pseudarthrosis (questionable fusion) shows lucency at the center of the cages with solid bone growth into the cage from each vertebral endplate. BSF-3: Radiographic fusion is indicated by bone bridges covering at least half of the fusion area, with bone density equal to or greater than at surgery. Fusion through one cage (half of the fusion area) is considered mechanically solid, even with lucency on the opposite side.

Data analysis

Statistical analyses were conducted using SPSS 24.0 (IBM, USA). Descriptive statistics are presented as mean ± standard deviation. One-way analysis of variance (ANOVA) was conducted to evaluate data involving multiple factors, including VAS-leg, VAS-back, and ODI (%) scores, measured at preoperative, 3 months, 12 months, 24 months, and final follow-up time points. Paired-sample t-tests were used to compare preoperative and final follow-up imaging parameters, such as lumbar lordosis, disc height, segmental lordosis angle, and foraminal area. Statistical significance was defined as $p < 0.05$.

Results

Demographic data

In this study, a cohort of 43 consecutive patients who underwent Endo-PLIF between February 2020 and March 2021 were included (Table 1). The cohort consisted of 22 females and 21 males (Table 2). The mean age of the cohort was 60.7 years, ranging from 39 to 77 years. Among the patients, 33 cases (76.7%) involved the L4–5 level, while 10 cases (23.3%) involved the L5–S1 level. Lumbar spondylolisthesis was identified in 4 patients, representing 9.3% of the total cohort. The average duration of symptoms was 4.6 years, ranging from 0.5 to 20 years. Additionally, 39 patients (90.6%) presented with at least one comorbidity, with 20 patients (46.5%) having at least 2 comorbidities. The most common comorbidity observed was cardiovascular disease (51.1%), followed by cerebrovascular disease (30.2%).

Table 1 Summary of demographic data

Patient	Gender, Age (y)	Stenosis level	Duration (y)	Comorbidities	Operation duration (min)	Height of the Cage (mm)	Pre-Op HGB (g/L)	Post-Op HGB (g/L)	Postoperative bed time (h)	MacNab evaluation	Complication
1	M,50	L4-5	10	U G	180	9	135	128	24	Excellent	
2	M,49	L4-5	1.2	C	240	10	161	138	18	Excellent	
3	F,66	L4-5	10	B C	300	9	141	117	32	Fair	Nerve root irritation
4	F,63	L4-5	20	E	250	10	142	146	20	Excellent	
5	F,69	L4-5	0.5	P	197	10	125	121	19	Excellent	
6	F,69	L4-5	1	B	270	10	120	112	24	Excellent	
7	M,77	L5-S1	0.5	C U	247	9	129	114	23	Good	
8	M,65	L4-5	1	C	280	10	124	114	19	Excellent	
9	M,68	L4-5	4	B C	240	10	145	136	15	Excellent	
10	F,50	L5-S1	6	P	234	12	136	103	24	Good	
11	F,55	L4-5	20	B C	235	9	135	128	18	Excellent	
12	F,39	L4-5	6		240	12	121	108	20	Excellent	
13	F,58	L4-5	1	E	238	9	160	114	24	Good	
14	M,66	L5-S1	0.5	U G	220	10	152	126	26	Excellent	
15	M,70	L4-5	10	E	189	10	141	125	32	Excellent	
16	M,52	L4-5	1	B C G	182	11	155	146	18	Excellent	
17	M,51	L5-S1	1	B	172	12	143	124	24	Good	
18	M,63	L5-S1	5	C	300	10	142	136	22	Good	
19	F,61	L4-5	10	B E	280	10	149	133	18	Excellent	
20	F,66	L4-5	6	C	261	9	132	122	18	Excellent	
21	M,57	L4-5	6	C P	241	9	159	135	20	Excellent	
22	M,71	L4-5	12	C	243	10	134	108	24	Good	
23	M,49	L4-5	10	B C P	187	10	135	128	22	Excellent	
24	F,65	L4-5	0.5	C H	300	10	145	138	24	Poor	Nerve root irritation
25	F,47	L4-5	0.5		164	12	132	130	19	Excellent	
26	F,70	L4-5	1	C	189	10	142	120	24	Excellent	
27	M,54	L4-5	6	B G	188	11	156	145	32	Excellent	
28	M,66	L5-S1	6	N	162	9	141	131	30	Good	
29	M,65	L5-S1	0.5	G	290	10	140	134	20	Good	
30	F,60	L4-5	8	C E	272	10	160	155	24	Excellent	
31	M,55	L4-5	8	U	190	11	133	120	20	Excellent	
32	M,72	L4-5	5	C	220	10	160	145	28	Excellent	
33	F,63	L4-5	0.5	B C	280	12	139	119	36	Fair	Nerve root irritation
34	F,64	L4-5	10	C U	260	10	145	144	24	Excellent	
35	F,65	L4-5	0.5		200	12	132	130	23	Excellent	
36	F,70	L4-5	2	N	265	10	122	109	18	Excellent	
37	M,72	L5-S1	0.5	B C U	255	10	109	108	26	Good	
38	M,54	L4-5	1	B C	245	10	124	115	25	Excellent	
39	M,66	L4-5	2	B C	245	10	145	138	24	Excellent	
40	F,52	L5-S1	1	P N	230	9	138	123	18	Good	
41	F,56	L4-5	1	C N	220	9	142	130	18	Excellent	
42	F,48	L4-5	0.5		210	12	125	110	24	Excellent	
43	F,62	L5-S1	2	C	241	9	135	116	22	Good	

Hemoglobin C, cardiovascular; B, cerebrovascular; E, endocrinologic; P, pulmonary; H, hepatobiliary; U, urologic; G, gastroenterology; N, neurology;

Table 2 Demographics of patients in this study

Clinical baseline characters	Value
Total patients, n	43
Age, years	60.7 ± 8.6
Gender, n	
Male	21 (48.8%)
Female	22 (51.2%)
Stenosis level, n	
L4-L5	33 (76.7%)
L5-S1	10 (23.3%)
Spondylolisthesis, n	4 (9.3%)
Operation duration, minutes	233.8 ± 38.6
Postoperative bed time, d	22.8 ± 4.5
Hospital stays, d	6.7 ± 2.3
Follow-up, months	24.4 ± 2.9
lumbar intervertebral fusion rate, n	39 (90.6%)

Table 4 Radiographic parameters

Parameters	Pre-Op	Last Follow-up	*P* Value
Lumbar lordosis (°)	43.42°±11.39°	47.98 ± 10.68°	0.173
Disc height (mm)	6.97 ± 1.65	9.87 ± 1.14	0.012*
SL (°)	4.42°±1.80°	5.53°±2.05°	0.352
Foraminal area (mm^2)	125.9 ± 23.1	178.8 ± 33.0	0.013*

SL, segmental lordosis angle; * indicates a significant difference

Clinical outcomes

All surgical procedures were completed successfully. The mean duration of the operations was 233.8 min, ranging from 162 to 300 min. The average preoperative hemoglobin level was 139.1 g/L, with a range of 109 to 161 g/L, while the average postoperative hemoglobin level was 126.1 g/L, ranging from 103 to 155 g/L. The average time to postoperative bed time and length of hospital stay were 22.9 h (ranging from 15 to 36 h) and 6.7 days (ranging from 5 to 11 days), respectively.

All patients experienced notable alleviation of both low back pain and leg pain, with significant improvements observed in ODI scores at 3, 12, and 24 months postoperatively, as well as during the last follow-up examination ($P < 0.001$). Preoperatively, the mean VAS scores for leg pain, back pain, and ODI were 7.44 ± 2.95, 7.05 ± 3.05, and 67.52 ± 9.31, respectively; these scores markedly improved postoperatively to 1.50 ± 0.42, 1.22 ± 0.54, and 20.42 ± 3.57, respectively, at the final follow-up evaluation (Table 3). The overall success of the procedures was assessed using the modified MacNab criteria. Upon evaluation at the final follow-up, outcomes were categorized as excellent for 29 patients (67.4%), good for 11 patients (25.6%), fair for 2 patient (4.6%), and poor for 1 patient (2.3%). In total, 93% of the patients achieved excellent or good outcomes. Representative cases are depicted in Fig. 3.

The preoperative and final follow-up imaging outcomes are delineated in Table 4. Disc height increased from 6.97 ± 1.65 mm preoperatively to 9.87 ± 1.14 mm at the last follow-up assessment ($P = 0.012$), with a mean disc height augmentation of 1.9 mm during the follow-up period. Additionally, the foraminal area expanded from 125.9 ± 23.1 mm^2 preoperatively to 178.8 ± 33.0 mm^2 at the last follow-up evaluation ($P = 0.013$), manifesting a

Table 3 VAS and ODI improvement

	Pre-Op	3 M Post-Op	12 M Post-Op	24 M Post-Op	Last Follow-up	*P* Value
VAS leg pain	7.44 ± 2.95	2.52 ± 0.52	1.37 ± 0.48	1.42 ± 0.55	1.50 ± 0.42	< 0.001*
VAS back pain	7.05 ± 3.05	2.63 ± 0.76	1.53 ± 0.51	1.61 ± 0.64	1.22 ± 0.54	< 0.001*
ODI%	67.52 ± 9.31	28.59 ± 7.58	22.38 ± 8.92	23.76 ± 7.53	20.42 ± 3.57	< 0.001*

* indicates a significant difference

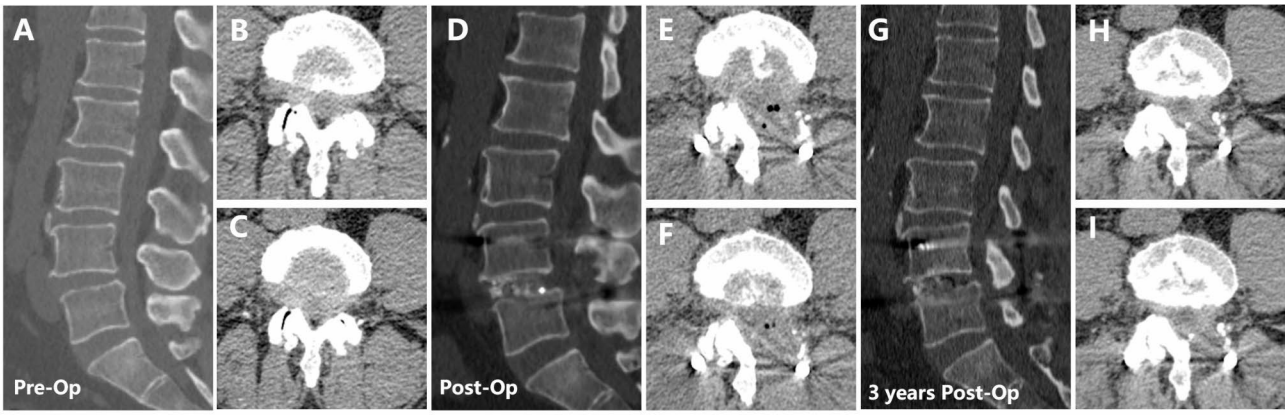

Fig. 3 Full-endoscopic posterior lumbar interbody fusion performed on a 63-year-old male patient diagnosed with degenerative lumbar spondylolisthesis. (**A**) Preoperative computed tomography (CT) on sagittal scans. (**B**-**C**) Preoperative CT on axial scans (L_{4-5}). (**D**) Postoperative CT on sagittal scans. (**E**-**F**) Postoperative CT on axial scans (L_{4-5}). (**G**) Final follow-up CT on sagittal scans. (**H**-**I**) Final follow-up CT on axial scans (L_{4-5})

mean foraminal area increase of 52.9 mm^2 postoperatively. However, the preoperative mean lumbar lordosis and segmental lordosis angle were 43.42°±11.39° and 4.42°±1.80°, respectively. At the final follow-up evaluation, the mean lumbar lordosis and segmental lordosis angle were 47.98 ± 10.68° and 5.53°±2.05°, respectively, with no statistically significant difference observed (Lumbar lordosis: $P = 0.173$, segmental lordosis angle: $P = 0.352$). Based on the BSF classification system, bone fusion was consecutively evaluated in 43 patients who underwent Endo-PLIF at the final follow-up. The results showed that 0 patients were classified as BSF-1, 4 patients (9.4%) as BSF-2, and 39 patients (90.6%) as BSF-3.

Complications

Prior literature has documented complications such as dural tear, nerve root injury, postoperative infection, and adjacent segment degeneration in lumbar spine surgery patients [15–17]. Our study found only three cases of postoperative nerve root irritation during follow-up. The patients experienced alleviation of pain symptoms following treatment with methylprednisolone and the neurotrophic agent adenosine cobalamin.

Discussion

Lumbar degenerative diseases is prevalent among elderly patients, often presenting with radicular pain, mechanical back pain, and intermittent claudication. While conventional open surgical approaches have historically been effective, there is a growing emphasis on enhanced recovery after surgery (ERAS) protocols [18]. Notably, Endo-PLIF mimics the decompression achieved by traditional open methods while utilizing a minimally invasive approach. Our study evaluates the efficacy of Endo-PLIF in managing Lumbar degenerative diseases, demonstrating that it consistently maintains satisfactory clinical outcomes over a minimum 2-year follow-up.

In our current investigation, the assessment based on the modified MacNab criteria revealed a combined excellent and good outcome proportion of 93% during the final follow-up examination. The average alleviation rates for VAS-back, VAS-leg, and ODI scores at the ultimate postoperative follow-up were 82.9%, 79.7%, and 70.1%, respectively. Previous studies [19–21] on Endo-PLIF for lumbar degenerative diseases have reported comparable clinical outcomes. Specifically, the average relief rates for VAS-back, VAS-leg, and ODI scores at the final postoperative follow-up ranged from 82.6 to 85.8%, 77.0–89.1%, and 56.1–69.6%, respectively. Thus, our clinical findings align closely with those reported in existing literature. Li-Ming et al. [22] reported the clinical outcomes of percutaneous endoscopic posterior lumbar interbody fusion (PE-PLIF). The satisfaction rate was 96.7%, the fusion rate was 93.3%, and the cage subsidence rate was 6.7%. These results are similar to our clinical outcomes. Endo-PLIF also shows similar clinical satisfaction outcomes compared to other minimally invasive fusion techniques, such as percutaneous endoscopic transforaminal lumbar interbody fusion (Endo-TLIF) [23–25], minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) [23, 26], and unilateral biportal endoscopic lumbar interbody fusion (ULIF) [27–29]. Moreover, compared to open posterior lumbar interbody fusion, Endo-PLIF yielded nearly identical improvement rates in VAS scores, fusion rates, and cage subsidence rates [22]. In the open PLIF group, the satisfaction rate was also 96.7%, while the fusion and cage subsidence rates were 96.7% and 16.7%, respectively [22]. However, this minimally invasive technique may enhance postoperative recovery by minimizing tissue trauma and blood loss [22].

Based on the BSF classification system, bone fusion was assessed in 43 patients who underwent Endo-PLIF at the final follow-up. The results indicated that 39 patients (90.6%) achieved BSF-3 status. The fusion rate of 90.6% observed in this study exceeds the reported rates for other fusion techniques combined with pedicle screw instrumentation, which typically range from 82.0–87.8% [30–33]. Endo-PLIF simulates the surgical approach of open surgery while providing the benefit of an enhanced field of view [13]. Importantly, a key advantage of Endo-PLIF is its ability to directly visualize the endplates, enabling optimal preparation and potentially improving fusion outcomes. Moreover, convenient fusion instruments play a critical role in the outcomes of fusion surgery. This study used a fusion channel with a direct diameter of 16 mm, allowing the passage of a cage up to 12 mm in height. This approach overcomes the limitations of traditional minimally invasive fusion surgeries, which are restricted by the small diameter of the working channel, preventing the insertion of larger cages. Additionally, developing new fusion instruments has further facilitated minimally invasive fusion procedures. Korean researcher Ping-Chi Tsai [34] reported replacing the working sheath with a larger, expandable Harrison cage glider. The Harrison cage-glider is available in various sizes, all of which are expandable. Notably, the spikes on this sheath assist in keeping the nerves safely outside the insertion path during cage placement.

In our study, disc height-related imaging variables and foraminal area were higher at the final follow-up than before surgery; however, no significant changes were found for segmental lordosis angle- and Lumbar lordosis-related variables. Shuangjun et al. [18] similarly observed a significant 2.3 mm enhancement in disc height postoperatively in open lumbar fusion surgery, mirroring the findings in our investigation. Conversely, Mengmeng et al. [7] noted no significant change in disc height within the lumbar fusion group postoperatively. The authors

suggest that these variations may be attributed to specific surgical techniques, including the type of intervertebral fusion cages employed, rod curvature, and longitudinal compression. Furthermore, our study revealed a postoperative increase in the foraminal area. The assessment of the foraminal area was conducted utilizing magnetic resonance imaging [35], which enables visualization of the soft tissue within the intervertebral foramen rather than merely the bony structures. The observed augmentation in the foraminal area is believed to be primarily attributed to the decompression effect resulting from the removal of the ligamentum flavum via the interlaminar approach, indirectly leading to foraminal enlargement. This mechanism differs from transforaminal lumbar interbody fusion, where direct enlargement of the foramen is achieved through the intervertebral foramen [36]. Additionally, the increase in intervertebral disc height may also contribute to a proportional expansion of the intervertebral foramen area. However, concerning the segmental lordosis angle, previous studies have indicated that enhancing this angle may decrease the likelihood of postoperative lower back pain [18]. However, our study did not observe a significant alteration in this parameter, suggesting the need for additional research data to explore this aspect further.

Several studies [19–21, 37] have documented complications associated with lumbar fusion technique, encompassing dural tears, postoperative dysesthesia, motor weakness, cage migration incision infection, and nonunion. In our investigation, three patients exhibited symptoms of postoperative nerve root irritation, presenting with lower limb radiating pain within the initial week post-surgery. After treatment with methylprednisolone and cobalamin adenosine, these symptoms were markedly ameliorated. We hypothesize that such symptoms may arise from repeated stimulation of nerve roots by surgical instruments during the procedure, particularly considering the relatively prolonged surgical duration for these three patients. Moreover, our investigation revealed a fusion rate of 90.6%, with the 4 cases experiencing fusion failure not displaying clinical symptoms correlated with lower back pain. Further cases are warranted to comprehensively summarize and analyze the complications associated with Endo-PLIF.

In the current study, Endo-PLIF has demonstrated preliminary efficacy in the treatment of lumbar degenerative diseases with a follow-up period of at least two years. We hypothesize that Endo-PLIF alleviates patients' pain symptoms through several mechanisms. First, endoscopic techniques relieve nerve compression by decompressing the disc, ligaments, and bony structures, achieving effective neural decompression [21]. Second, in some patients with lumbar spondylolisthesis or spinal instability, Endo-PLIF restores stability through interbody fusion [21]. Third, for patients with discogenic low back pain, Endo-PLIF addresses the root cause of pain by treating the degenerated and deteriorated discs, reducing chemical irritation to the nerves, and ultimately providing pain relief [38]. Endo-PLIF likely involves a combination of mechanisms, including the biomechanical stabilization of the lumbar spine, neuroelectrophysiological changes, and molecular biological processes. Further research is needed to explore these mechanisms in more detail.

One limitation of this study is its relatively small sample size, treated by a single surgeon. Large-scale multicenter studies are needed to validate our findings across diverse populations. A small sample size in retrospective studies can limit the generalizability of findings, reducing representativeness and robustness, and increasing susceptibility to sampling errors and biases. To enhance reliability and generalizability, we plan to validate the findings with more rigorous statistical methods and a larger sample size. Additionally, the procedure was performed only on selected patients, thus its applicability to a broader population warrants further investigation. Furthermore, potential interobserver bias in radiological measurements should also be considered when interpreting the results.

Conclusion

Endo-PLIF can achieve favorable clinical outcomes in the treatment of patients with lumbar degenerative disease in this minimum two-year follow-up study. However, further extensive, long-term, multicenter studies are necessary to validate these findings.

Author contributions

Lihui Yang and Baodong Wang wrote the main manuscript text, Shuo Yuan and Qichao Wu prepared Figs. 1, 2 and 3, Peng Du and Ning Fan prepared Tables 1, 2, 3 and 4.All authors reviewed the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

This study was approved by the ethics committee of Beijing Chaoyang Hospital, Capital Medical University (Registration number: 2022-KE-645) and the research was performed in accordance with the guidelines of the Declaration of Helsinki. Informed consent for this study was obtained from all patients by both written and verbal.

Competing interests

The authors declare no competing interests.

Conflict of interest

Lihui Yang, Baodong Wang, Lei Zang, Peng Du, Shuo Yuan, Ning Fan, and Qichao Wu declare that they have no conflict of interest.

Authorship
All named authors meet the International Committee of Medical Journal Editors (ICMJE) criteria for authorship for this article, take responsibility for the integrity of the work as a whole, and have given their approval for this version to be published.

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