

CLINICAL ARTICLE

Clinical Effect of Minimally Invasive Microendoscopic-Assisted Transforaminal Lumbar Interbody Fusion for Single-Level Lumbar Disc Herniation

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Objective: This retrospective study aimed to compare the clinical and radiological outcomes of transforaminal lumbar interbody fusion (TLIF) through the Wiltse approach (W-TLIF) vs minimally invasive microendoscopy-assisted transforaminal lumbar interbody fusion (ME-TLIF) in single-segment lumbar disc herniation (LDH).

Methods: A retrospective study was conducted to study the differences in specific clinical outcomes between single-segment LDH patients receiving W-TLIF and ME-TLIF. Single-segment LDH patients admitted to the Fujian Medical University Union Hospital from March 2015 to June 2018 were included.

All the participants were divided into the ME-TLIF group or the W-TLIF group according to their TLIF surgery types. Demographic characteristics, the visual analog score (VAS), Oswestry Disability Index (ODI), Japanese Orthopaedic Association (JOA) scale, blood loss volume, postoperative drainage, ambulated time, initial postoperative back pain, hospitalization duration, expenses, and improvement rates of patients in the two groups were collected for analysis. Radiographic fusion was ultimately assessed via the Bridwell interbody fusion grading system. All selected patients with TLIF were followed up for 1 year.

Results: Fifty-seven patients were selected, with 26 in the ME-TLIF group and 31 in the W-TLIF group, both of whom were followed up for 1 year. The mean age of the included patients was 53.75 ± 9.313 years, and the sex ratio was indiscriminate. There was no significant difference in demographic data or operating time between the two groups prior to surgery. The blood loss volume (ME-TLIF: 228.5 vs W-TLIF: 681.3), postoperative drainage (ME-TLIF: 82.1 ± 23.5 vs W-TLIF: 345.8 ± 65.2), initial postoperative back pain (ME-TLIF: VAS_3 days: 1.96 ± 0.60 VAS_7 days: 1.73 ± 0.53 , W-TLIF: VAS_3 days: 2.48 ± 0.51 VAS_7 days: 1.87 ± 0.43), and hospitalization duration (ME-TLIF: 9.04 vs. W-TLIF: 11.29) were all significantly lower in the ME-TLIF group ($p < 0.05$). However, there were no statistical differences between the two groups in VAS, ODI, and JOA at 1 month, 3 months, 6 months, and 1 year post-operatively ($p > 0.05$). The fusion rates of the two groups showed no notable difference ($p > 0.05$), while the X-ray exposure time in the ME-TLIF group was significantly longer than in the W-TLIF group ($p < 0.05$).

Conclusions: ME-TLIF surgery was an effective and satisfactory surgical technique to manage LDH. Although ME-TLIF increased the operation time and intraoperative fluoroscopic irradiation volume, it could effectively relieve low back pain from early postoperative onset and promote early postoperative recovery compared with W-TLIF.

Key words: clinical outcomes; micro-endoscopic assistance; minimally invasive; single-level lumbar disc herniation; transforaminal lumbar interbody fusion

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Introduction

Lumbar disc herniation (LDH) with lumbar instability is a common cause of low back pain, radiculopathy, and/or neurogenic claudication.^{1,2} Patients with LDH prefer to choose surgical decompression of the neural elements and stabilize spinal fusion after invalid non-operative treatment.^{3,4} Currently, transforaminal lumbar interbody fusion (TLIF) and posterior lumbar interbody fusion (PLIF) are two widely used types of surgery for LDH therapy.⁵⁻⁷ The indications for lumbar interbody fusion mainly include: low back pain, lumbar disc herniation, neurogenic claudication, radiculopathy due to foraminal stenosis, spinal instability, and lumbar degenerative spinal deformity that includes symptomatic spondylolisthesis, and degenerative scoliosis.⁸⁻¹⁰ The carragee grading as shown in Figure 1 is helpful in understanding disc herniation and nerve root compression. Cloward firstly proposed PLIF surgery in the 1940s,¹¹ but Styf and Willén revealed that PLIF surgery would dissect intraoperative paravertebral muscles in a wide range and lead to dural tear, nerve injury, or epidural scarring due to decompression and fixation.¹² To reduce paraspinal muscle injury and promote postoperative recovery, Harms and Rollinger introduced transforaminal lumbar interbody fusion (TLIF) surgery in 1982,¹³ which has become a popular and well-established technique. TLIF surgery enters along the intermuscular space of the multifidus and longus muscles into low back, and it requires extensive intraoperative dissection and retraction of the paraspinal muscular ligamentous unit,¹⁴⁻¹⁶ which can result in local muscle necrosis, fibers scarring, and increased incidence of low back pain (LBP).¹⁷⁻¹⁹

The minimally invasive spine surgery innovation and advanced devices promote the minimally invasive TLIF in LDH.^{20,21} Thus, Foley *et al.* first proposed minimally invasive TLIF aiming to reduce and avoid intraoperative multifidus stripping and stretching.²² While ME-TLIF induces less damage to paravertebral muscles and has better

postoperative outcomes compared with conventional TLIF, several studies reported several limitations of ME-TLIF, including incomplete decompression and longer radiation exposure and operation time.^{16,23,24} In 2005, Isaacs²⁵ pioneered the use of endoscopic discectomy and interbody fusion techniques with intraoperative blunt distension that could better protect the multifidus muscle, paraspinal muscles, and surrounding soft tissue from injury.

However, limited studies have focused on the differences in clinical effects between ME-TLIF and W-TLIF in treating patients with single-stage LDH. Since 2015, our institution has performed ME-TLIF surgery with micro-endoscopic assistance for LDH. This technique can provide adequate light, 10 times the maximum vision field, and clearer surgical vision field. The tubular working channel can be angled directly to facilitate direct decompression of other areas, such as the contralateral nerve root canal.²⁶ Furthermore, ME-TLIF surgery has a varied range of surgery applications, including lumbar spinal stenosis, lumbar disc herniation, degenerative lumbar spondylolisthesis.^{16,27} Therefore, this study aimed to: (1) compare the perioperative data, clinical results, and imaging findings of ME-TLIF and W-TLIF in the treatment of single-stage LDH; (2) determine the advantages of ME-TLIF surgical method and understand the shortcomings of this method; (3) provide clinical case support for the application of the ME-TLIF surgical method.

Methods

Participants and Study Design

This is a retrospective study approved by the Ethics Committee of Fujian Medical University Union Hospital (Ethical approval Number: 2020KY0116). Single-segment LDH patients admitted to the Fujian Medical University Union Hospital from March 2015 to June 2018 were included. All

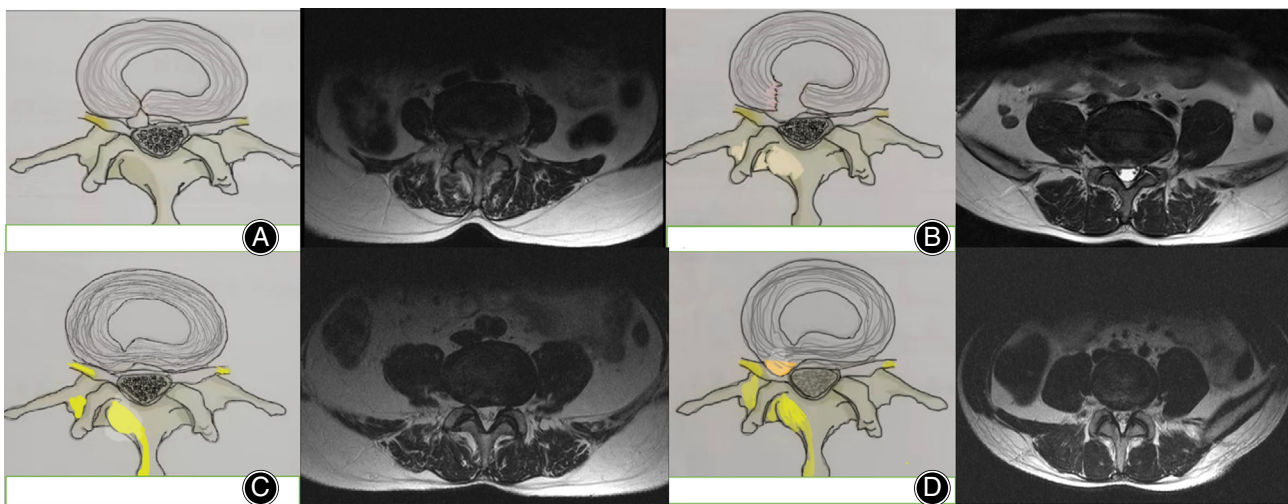


Fig. 1 Carragee grading. The carragee grading of lumbar disc herniation is based on the case of fragmented blocks, as demonstrated by cartoon and MR: (A) block-crack type; (B) block-defect type; (C) block-inner type; (D) no crushed block-inner type

the participants were diagnosed with single-segment LDH based on image examination. All data were collected postoperatively from an electronic medical record system and included patients were followed up for 1 year. Participants were included according to the following criteria: (1) all patients presented with back or radicular pain refractory and received physical or medical treatment for 4–8 weeks; (2) patients had a preoperative evaluation with a detailed neurological examination and radiological examinations, including dynamic lumbar radiography (flexion and extension) and static (anterior–posterior and lateral), lumbar MRI, or CT. Participants were excluded according to the following criteria: (1) patients with multi-level lumbar disk degeneration; (2) patients with previous lumbar spine surgery; and (3) patients with diagnoses of spine fractures, tumors, and infections or acute spinal trauma.

Data Preparation and Collection

Before clinical data collection, written informed consent from all the patients was obtained. Demographic characteristics, including age, gender, body mass index (BMI), and comorbidities before surgery were recorded for later analysis. Ultimately, detailed information about neurological examination, outcome measures, and clinical evaluation of TLIF were collected as well.

Outcome Measures

Perioperative outcomes measurements, including operation duration (min), blood loss volume (mL), fluoroscopic time (seconds), postoperative drainage (mL), ambulation time (walking 10 m independently), hospitalization duration (days), hospitalization expenses (RMB), and blood transfusion rate, were compared between the ME-TLIF and W-TLIF groups.

Clinical Evaluation of TLIF

Oswestry Disability Index (ODI)

Oswestry Disability Index (ODI) 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 (consisting 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, take the highest score. If all 10 sections are completed, the score is calculated as follows: total scored out of total possible score $\times 100$. If one section is missed (or not applicable), the score is calculated as: $(\text{total score} / (5 \times \text{number of questions answered})) \times 100\%$. A score of 0%–20% is considered mild dysfunction, 21%–40% is considered moderate dysfunction, 41%–60% is considered severe dysfunction, and 61%–80% is considered disability. For cases with a score of 81%–100%,

they are either long-term bedridden or exaggerating the impact of pain on their lives.²⁸

Pain Measurement (Visual Analog Scale)

The outcomes of symptoms were evaluated through follow-up interviews at 6 weeks, 6 months, and 1 year after surgery. Low back pain and leg pain were measured using the Visual Analog Scale (VAS) score. It is a continuous scale with a score of zero representing no pain and a score of 10 representing the worst pain.²⁹

Assessment of the Severity of Clinical Symptoms (JOA Scores)

Japanese Orthopaedic Association (JOA) scores were used to assess the severity of clinical symptoms. It is comprised of six domain scores, which are motor dysfunction in the upper extremities, motor dysfunction in the lower extremities, sensory function in the upper extremities, sensory function in the trunk, sensory function in the lower extremities, and bladder function, scaling from 0 to 4, 4, 2, 2, 2, and 3, respectively. The minimum total score is zero and the maximum total score is 17.

The following indicators were conducted to accomplish the clinical evaluation of TLIF: ODI, VAS scores for back pain and leg pain, JOA scores, and the JOA recovery rate (%). They were performed to assess the preoperative and postoperative pain in the back and legs and daily life functions. Data were collected before the operation, at 1 month, 3 months, 6 months, and 1 year after surgery. VAS data for back pain 3 and 7 days after surgery were collected. Postoperative complications were also recorded (e.g., urinary tract infection, deep venous thrombosis, or surgical site infection).

Surgical Techniques

For both groups of patients, the operation was performed by the same surgeons. The W-TLIF utilized a midline open approach and notched a single incision through the Wiltse bilateral approach. Subcutaneous tissue was exposed through the intervertebral joint bilateral muscle space, and the assist of the lamina. The operator avoided extensive peeling of the paraspinal musculature and preserved well posterior ligamentous complex.³⁰

Minimally invasive surgical instruments for the MET-Rx Microsightoscopy System (Medtronic), Viper1 Percutaneous Pedicle Screw Internal Syndromes (DePuy), and Concorde bullet intervertebral fusion and minimally invasive surgical instruments (DePuy) were applied for the implementation of ME-TLIF. A representative case and ME-TLIF surgery operation are shown in Figure 2. The surgical steps were as follows:

1. Operative position. Patients were given general anesthesia and then were placed in a prone position.
2. Nailing positioning. The center of the vertebral pedicle was identified by the needle of the c-shaped arm X-ray.
3. Clearance of the disc. With the help of the perspective, the Jamshidi needle was placed in the outer part of the

pedicle (3 o'clock or 9 o'clock position) and slowly pulled out the needle core via the MET-Rx microendoscopic system. The intervertebral disc tissue was cleaned.

4. Implant Cage. The cage filled with the cancellous bone was then inserted obliquely into the intervertebral space through the working cannula.

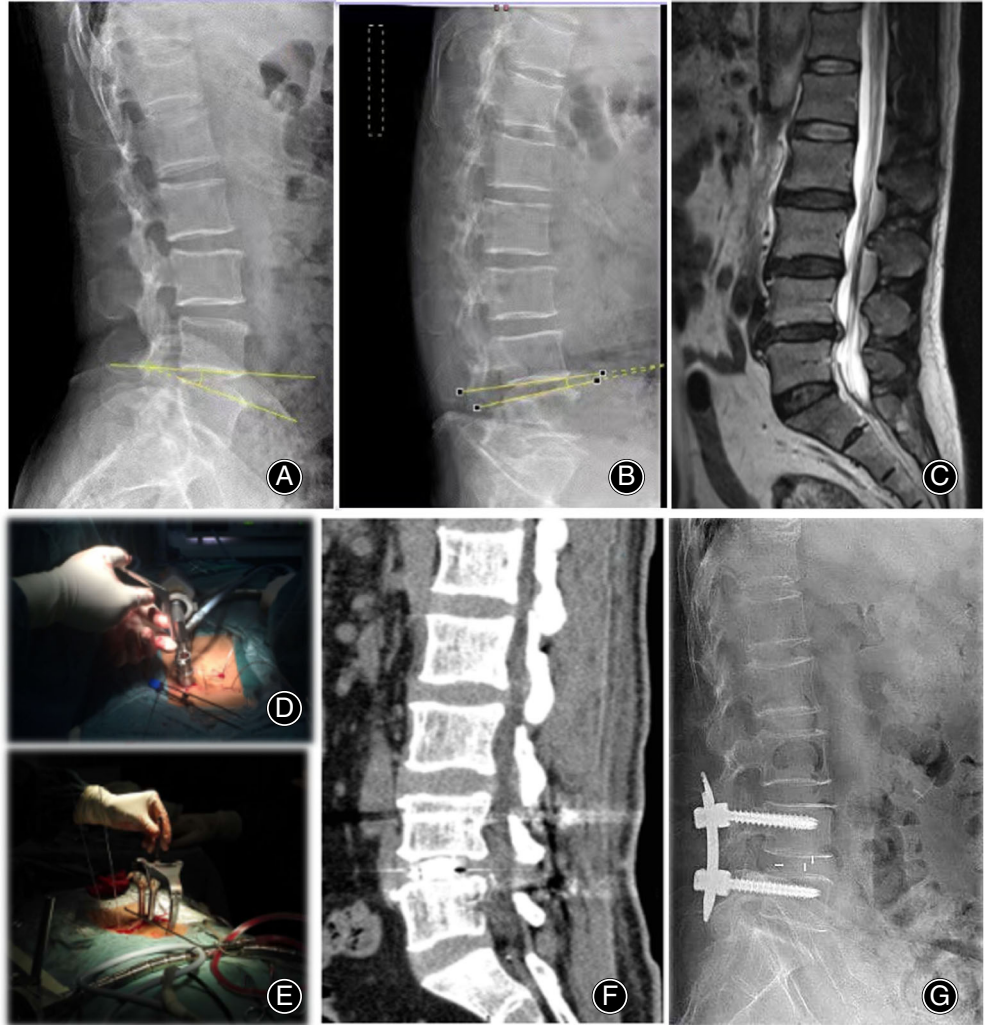


Fig. 2 A 44-year-old man was admitted into our hospital for low back pain and radiating pain of lower limb for almost 1 year. (A), (B), and (C): The preoperative image of the patient showed lumbar disc herniation combined with instability in L4/5 level. (D) and (E): showed the ME-TLIF surgery operation. (F) and (G): It showed complete decompression after unilateral approach for spinal canal decompression

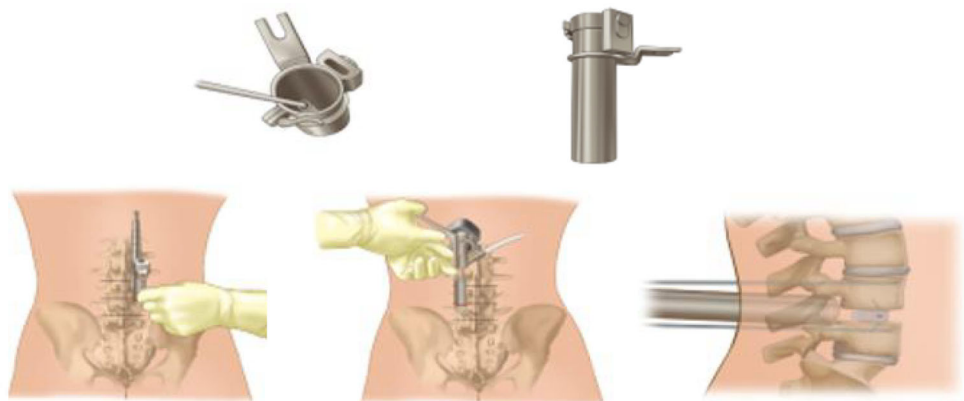


Fig. 3 Minimally invasive surgical instruments for the MET-Rx Microsightoscopy System (Medtronic) and a brief description of surgery procedure

5. Set Screw. After removing the MET-Rx working channel, the guide needle was percutaneously expanded, then a 6 mm Viperl pedicle screw was screwed and tapped. We used the same method to screw in the other three screws. An appropriate length of the rod was inserted into the subcutaneous tissue. Then the stick was removed and the nut was screwed. The same method was applied to the opposite side.

The visualization process of surgery is shown in Figure 3.

Statistical Analysis

All data were collected retrospectively. Statistical analysis was performed using the SPSS version 10.0. Continuous variables were described as mean \pm standard deviation ($\bar{x} \pm s$) and the categorical variables were presented as sum and percentage ($n, \%$). The Pearson chi square test or Fisher exact test were

TABLE 1 Demographic characteristics of included patients

Variables	Total	ME-TLIF (N = 26)	W-TLIF (N = 31)	t value	p
Gender				0.381	0.771
Female	26 (45.6%)	11 (42.3%)	15 (48.4%)		
Male	31 (54.4%)	15 (57.7%)	16 (51.6%)		
Age (years)	53.8 \pm 9.3	54.3 \pm 9.4	53.3 \pm 9.4	0.408	0.685
BMI (kg/m ²)	23.4 \pm 2.71	23.4 \pm 2.84	23.4 \pm 2.65	0.037	0.971
Menopause				0.052	0.923
No	42 (73.4%)	18 (69.2%)	24 (77.4%)		
Yes	15 (26.3%)	8 (30.8%)	7 (22.6%)		
Smoking				1.068	0.121
No	48 (84.2%)	19 (73.1%)	29 (93.5%)		
Yes	9 (15.8%)	7 (26.9%)	2 (6.5%)		
Comorbidities					
Surgical history				0.540	0.685
No	44 (77.2%)	19 (73.1%)	25 (80.6%)		
Yes	13 (22.8%)	7 (26.9%)	6 (19.4%)		
Hypertension				0.540	0.682
No	44 (77.2%)	19 (73.1%)	25 (80.6%)		
Yes	13 (22.8%)	7 (26.9%)	6 (19.4%)		
Diabetes				0.892	0.458
No	47 (82.5%)	20 (76.9%)	27 (87.1%)		
Yes	10 (17.5%)	6 (23.1%)	4 (12.9%)		
Heart disease				<0.0001	0.999
No	46 (80.7%)	21 (80.8%)	25 (80.6%)		
Yes	11 (19.3%)	5 (19.2%)	6 (19.4%)		
Comorbidities				1.238	0.231
No	47 (82.5%)	24 (92.3%)	23 (74.2%)		
Yes	10 (17.5%)	2 (7.7%)	8 (25.8%)		
Lower limb joint disease				0.482	0.728
No	55 (96.5%)	26 (100%)	29 (93.5%)		
Yes	2 (3.5%)	0 (0.00%)	2 (6.5%)		
Osteoporosis				1.923	0.103
No	33 (57.9%)	19 (73.1%)	14 (45.2%)		
Yes	24 (42.1%)	7 (26.9%)	17 (54.8%)		
Preoperative hemoglobin	13.9 \pm 1.49	14.4 \pm 1.1	13.5 \pm 1.65	2.582	0.058

Abbreviations: BMI, body mass index; ME-TLIF, microendoscopy-assisted transforaminal lumbar interbody fusion; W-TLIF, Wiltse approach-transforaminal lumbar interbody fusion

TABLE 2 Comparison of preoperative scale scores in two groups

Variables	Total	ME-TLIF (N = 26)	W-TLIF (N = 31)	t value	p
VAS (back)	7.49 \pm 0.80	7.62 \pm 0.85	7.39 \pm 0.76	1.058	0.290
VAS (leg)	6.75 \pm 0.69	7.31 \pm 0.84	6.71 \pm 0.59	2.381	0.065
ODI, median (Q1, Q3)	24.91 [23.0;26.5]	25.62 [22.75;28.00]	24.32 [23.0;26.0]	1.235	0.214
JOA	13.75 \pm 1.79	13.23 \pm 1.73	14.19 \pm 1.74	1.750	0.123

Abbreviations: JOA, Japanese Orthopedic Association; ME-TLIF, microendoscopy-assisted transforaminal lumbar interbody fusion; ODI, Oswestry Disability Index; VAS, visual analog score; W-TLIF, Wiltse approach-transforaminal lumbar interbody fusion

used for categorical data. Student *t*-test and chi-square were performed for statistical comparison between the two groups. Multivariate analysis of variance was conducted for VAS, ODI, and JOA score comparisons at different time points. A $p < 0.05$ was considered statistically significant.

Results

Demographic Characteristics of Included Patients

Fifty-seven patients were included in the study, with 26 eligible patients in the ME-TLIF group and 31 eligible patients in the W-TLIF group. No patients were excluded due to incomplete follow-up data. Table 1 and Table 2 describe the demographic characteristics of patients in the two groups. There were no statistical differences in terms of age, gender, body mass index, lumbar fusion position, scores of scales, and comorbidities between the two groups ($p > 0.05$).

TABLE 3 Lumbar levels fusion grade description

Grade Description	
I	Fused with remodeling and trabeculae present
II	Graft intact, not fully remodeled and incorporated, but no lucency present
III	Graft intact, potential lucency present at top and bottom of graft
IV	Fusion absent with collapse/resorption of graft

Intraoperative Findings

The details of the operation were as follows: (1) When placing the working channel, special attention should be paid to two details: (a) for fluoroscopy positioning and Orth fluoroscopy, it was very important to accurately place the working channel on the lower edge of the lamina of the upper vertebral body because it could reduce unnecessary operations to the target space. For lateral fluoroscopy, it should be parallel to the direction of intervertebral space so that damage to the bony endplate could be avoided when dealing with the endplate. (b) For beauty, a transverse incision could be made along the position of one of the positioning Kirschner wires. At the same time, the incision should not be too large. In addition to beauty, it was more important to avoid channel swing caused by too large incision. (2) During decompression, the lower articular process could be removed with a bone knife. At this time, attention should be paid to controlling the depth to avoid too deep damage to the upper articular process. (3) Finally, when the embedded Kirschner wire was inserted into the percutaneous pedicle screw right after fusion cage insertion, the Kirschner wire should not be brought into the deep part to avoid damage to the anterior organs.

Comparison of Postoperative Metrics

Blood Loss, Operation Duration, and Fluoroscopy Time

Intraoperative blood loss and postoperative drainage in the ME-TLIF group were significantly less than those in the

TABLE 4 Perioperative metrics comparison of included patients

Variables	Total	ME-TLIF (N = 26)	W-TLIF (N = 31)	t value	p
Hospitalization expenses, median (Q1, Q3)	RMB 61,420 [55,596;68,810]	RMB 65,666 [62,598;72,446]	RMB 57,859 [53,009;61,509]	1.089	0.285
Postoperative hemoglobin	11.7 ± 1.60	12.6 ± 1.28	10.9 ± 1.48	2.898	0.012
Change of hemoglobin level (Preoperative hemoglobin-Postoperative hemoglobin)	2.237 ± 1.054	1.869 ± 0.992	2.545 ± 1.019	2.531	0.0145
Operation duration (min), median (Q1, Q3)	278 [253;307]	298 [261;315]	263 [222;285]	2.969	0.004
Blood loss volume (ml), median (Q1, Q3)	474.7 [150;600]	228.5 [100;225]	681.3 [300;800]	4.148	<0.001
Fluoroscopy time (s), median (Q1, Q3)	18.9 [13.0;68.0]	71.2 [67.8;71.2]	14.4 [13.0;15.0]	4.272	<0.001
Postoperative drainage (ml)	213.9 ± 38.3	82.1 ± 23.5	345.8 ± 65.2	3.812	<0.001
Postoperative active time (days)				3.958	<0.001
2	8 (14.0%)	8 (30.8%)	0 (0.00%)		
3	28 (49.1%)	16 (61.5%)	12 (38.7%)		
4	19 (33.3%)	2 (7.7%)	17 (54.8%)		
5	2 (3.51%)	0 (0.00%)	2 (6.5%)		
Postoperative complications				1.012	0.354
No	54 (94.74%)	26 (100%)	28 (90.32%)		
Yes	3 (5.26%)	0 (0.00%)	3 (9.68%)		
Spinal fusion position (n, %)				2.015	0.034
L3-4	2 (3.50%)	0 (0.00%)	2 (6.4%)		
L4-5	36 (63.2%)	22 (84.6%)	14 (45.2%)		
L5-S1	19 (33.3%)	4 (15.4%)	15 (48.4%)		
Hospitalization duration (days), median (Q1, Q3)	10.26 [8.00;12.00]	9.04 [8.00;10.00]	11.29 [8.00;12.00]	2.535	0.0143

Abbreviations: ME-TLIF, microendoscopy-assisted transforaminal lumbar interbody fusion; W-TLIF, Wiltse approach-transforaminal lumbar interbody fusion

W-TLIF group ($p < 0.05$). All patients did not receive postoperative or intraoperative blood transfusions. The time lengths of intraoperative fluoroscopy were significantly longer in the ME-TLIF group than in the W-TLIF group, with a medium of 71.2 s in the ME-TLIF group and 14.4 s in the W-TLIF group, respectively ($t = 4.272$, $p < 0.001$). The operation duration in the ME-TLIF group was longer than that in the W-TLIF group ($t = 2.969$, $p < 0.05$) (Table 4). Tables 3, 4, and 5 described the spine and lumbar level fusion of patients in the two groups, and it showed a statistical difference between the two groups in spinal fusion position ($t = 2.015$, $p < 0.05$).

Duration of Hospitalization and Other Outcomes

Duration of fluoroscopy time: The median fluorescence time was 71.2 s and 14.4 s in the ME-TLIF group and the W-TLIF group, respectively ($t = 4.272$, $p < 0.001$). In the ME-TLIF group and the W-TLIF group, the average of postoperative drainage was 82.1 ± 23.5 ml and 345.8 ± 65.2 ml, respectively ($t = 3.812$, $p < 0.001$). The median of hospitalization expenses was 65,666 RMB in the ME-TLIF group and 57,859 RMB in the W-TLIF group, respectively, and there was no significant difference between the two groups ($t = 1.089$,

$p > 0.05$). Postoperative hemoglobin was 12.6 ± 1.28 in the ME-TLIF group and 10.9 ± 1.48 in the W-TLIF group, respectively ($t = 2.898$, $p < 0.05$). Change of hemoglobin level after the surgery was 1.869 ± 0.992 in the ME-TLIF group and 2.545 ± 1.019 in the W-TLIF group, respectively ($t = 2.531$, $p < 0.05$). Component ratio of postoperative complications time were that in the ME-TLIF group, 26 people had no complications (100%), zero people had complications (0%), and in the W-TLIF group, 28 people had no complications (90.32%), and three had complications (9.68%), with no significant difference between the two groups ($t = 1.012$, $p > 0.05$).

The median number of hospitalization days was 9.04 in the ME-TLIF group and 11.29 in the W-TLIF group, respectively ($t = 2.535$, $p < 0.05$).

Clinical Outcomes Comparison of Included Patients

Oswestry Disability Index (ODI), Japanese Orthopaedic Association (JOA), and visual analog score (VAS)

Patients in the ME-TLIF and W-TLIF groups were followed up for 1 year. ODI, JOA, and VAS scores at the latest visit

TABLE 5 VAS of back and leg pain comparison of included patients

Variables	Total	ME-TLIF (N = 26)	W-TLIF (N = 31)	t value	p
Lumbar levels fusion 6 month				0.038	0.923
I	33 (57.9%)	16 (61.5%)	17 (54.80%)		
II	24 (42.1%)	10 (38.5%)	14 (45.20%)		
Lumbar levels fusion 12 month				0.712	0.632
I	51 (89.47%)	24 (92.31%)	27 (87.1%)		
II	6 (10.53%)	2 (7.69%)	4 (12.9%)		
JOA recovery rate				1.238	0.25
<75%	13 (22.8%)	3 (11.5%)	10 (32.3%)		
≥75%	44 (77.2%)	23 (88.5%)	21 (67.7%)		
VAS_3 days (back)	2.25 ± 0.61	1.96 ± 0.60	2.48 ± 0.51	2.352	0.024
VAS_7 days (back)	1.81 ± 0.48	1.73 ± 0.53	1.87 ± 0.43	1.985	0.038

Abbreviations: JOA, Japanese Orthopaedic Association; ME-TLIF, microendoscopy-assisted transforaminal lumbar interbody fusion; VAS, visual analog score; W-TLIF, Wiltse approach-transforaminal lumbar interbody fusion

TABLE 6 Comparison of postoperative scores between the two groups

Group	Time	ODI	JOA	VAS (back)	VAS (leg)
ME-TLIF	Preoperation	$25.62 \pm 4.54^{a,b,c}$	$13.23 \pm 1.73^{a,b,c}$	$7.62 \pm 0.85^{a,b,c}$	$7.03 \pm 0.83^{a,b,c}$
	3 months	$5.58 \pm 0.64^{b,c,d}$	$25.23 \pm 0.76^{c,d}$	1.46 ± 0.58^d	1.46 ± 0.58^d
	6 months	$3.58 \pm 1.17^{a,d}$	$25.46 \pm 0.90^{c,d}$	1.31 ± 0.47^d	1.31 ± 0.47^d
	1 year	$3.23 \pm 1.18^{a,d}$	$25.92 \pm 0.98^{a,b,d}$	1.23 ± 0.59^d	1.23 ± 0.59^d
W-TLIF	Preoperation	$24.32 \pm 3.19^{a,b,c}$	$14.19 \pm 1.74^{a,b,c}$	$7.39 \pm 0.76^{a,b,c}$	$6.71 \pm 0.59^{a,b,c}$
	3 months	$5.13 \pm 0.92^{b,c,d}$	$24.97 \pm 0.88^{c,d}$	$1.39 \pm 0.50^{c,d}$	$1.39 \pm 0.50^{c,d}$
	6 months	$4.13 \pm 0.67^{a,d}$	$25.19 \pm 1.01^{c,d}$	1.23 ± 0.43^d	1.23 ± 0.43^d
	1 year	$3.90 \pm 0.70^{a,d}$	$25.77 \pm 1.26^{a,b,d}$	$1.13 \pm 0.43^{a,d}$	$1.13 \pm 0.43^{a,d}$

Abbreviations: JOA, Japanese Orthopaedic Association; ME-TLIF, microendoscopy-assisted transforaminal lumbar interbody fusion; ODI, Oswestry Disability Index; VAS, visual analog score; W-TLIF, Wiltse approach-transforaminal lumbar interbody fusion; ^a Compared with 3 months after surgery, $p < 0.05$; ^b Compared with 6 months after surgery, $p < 0.05$; ^c Compared with 1 y after surgery, $p < 0.05$; ^d Compare with pre-operation, $p < 0.05$.

were better than those before the surgery in both groups ($p < 0.05$). Postoperative VAS of back pain in the ME-TLIF group on day 3 and 7 were significantly less than those in the W-TLIF group ($p < 0.05$). However, there were no differences

in postoperative pain at other observed time points between the two groups. There were also no significant differences in JOA, JOA recovery rate, and ODI score between the two groups at all time points after surgery (Tables 5 and 6).

TABLE 7 Bony fusion outcomes at 6 month comparison of included patients

Latest visit bony fusion	ME-TLIF (n = 26)	W-TLIF (n = 31)	χ^2	p
I	16 (61.50%)	17 (54.8%)	0.001	0.923
II	10 (38.5%)	14 (45.2%)		
III	0 (0.00%)	0 (0.00%)		
IV	0 (0.00%)	0 (0.00%)		

Abbreviations: ME-TLIF, microendoscopy-assisted transforaminal lumbar interbody fusion; W-TLIF, Wiltse approach-transforaminal lumbar interbody fusion

TABLE 8 Bony fusion outcomes at 1 year follow-up comparison of included patients

Latest visit bony fusion	ME-TLIF (n = 26)	W-TLIF (n = 31)	χ^2	p
I	24 (92.31%)	27 (87.1%)	0.001	0.632
II	2 (7.69%)	4 (12.9%)		
III	0 (0.00%)	0 (0.00%)		
IV	0 (0.00%)	0 (0.00%)		

Abbreviations: ME-TLIF, microendoscopy-assisted transforaminal lumbar interbody fusion; W-TLIF, Wiltse approach-transforaminal lumbar interbody fusion

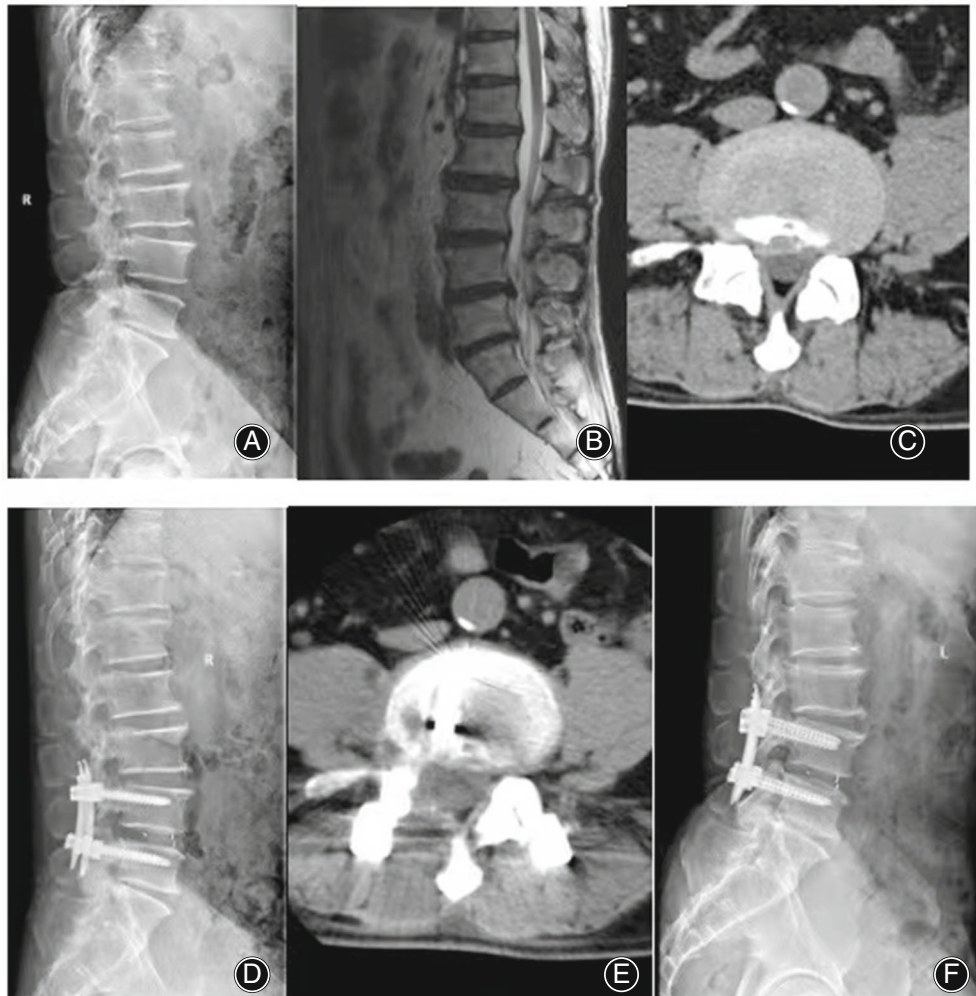


Fig. 4 A 63-year-old man was admitted to our hospital for low back pain. Conservative treatment for low back pain was ineffective for at least 6 months. (A)–(C): The preoperative image data of the patient showed degenerative disc disease in L4/L5 level. (D) and (E): Lateral radiograph and CT scan showing the internal fixation and cage the third day after microendoscopy-assisted transforaminal lumbar interbody fusion. (F) Lateral radiograph showing a solid fusion 1 year after surgery

Bony Fusion Outcomes Comparison of Included Patients

In terms of bony fusion, radiographs were used as the measurement method. Based on Bridwell's criterion, at 6 months, 61.50% of patients achieved grade I fusion and 38.50% of patients achieved grade II fusion in the ME-TLIF group. A total of 54.80% of patients achieved degree I fusion and 45.20% of patients achieved grade II in the W-TLIF group ($p = 0.923$) (Table 7). After 1 year, 92.31% of patients in the ME-TLIF group and 87.1% of patients in the W-TLIF group achieved grade I fusion ($p = 0.632$) (Table 8). All of the above showed no statistical differences between the two groups. The patients with grade II fusion are still under follow-up. A representative case is shown in Figure 4.

Complications in the Two Groups

There were no patients who suffered severe life-threatening complications on account of the surgery. However, three perioperative complications were reported in the W-TLIF group. The right L5 root palsy of one case had no significant improvement after operation because the pedicle position was compressed by the thecal sac. As a result, she experienced a revision operation that rearranged the pedicle screws and finally recovered completely within 3 months after the operation. One patient was recorded with a urinary tract infection but was successfully treated with antibiotics. The third case had a superficial wound because of an injection and was given dressing nursing every day. Two weeks later, the wound healed well, and the patient was successfully discharged.

Discussion

The Superiority of the MIS-TLIF

In order to reduce the damage to posterior midline spinal structures, Foley *et al.* introduced the concept of minimally invasive TLIF, a modification of PLIF,²² which had less damage to paravertebral muscles compared with conventional TLIF. In 2005, Mummaneni³¹ proposed the application of Medtronic's expandable minimally invasive approach for minimally invasive TLIF surgery. Yan *et al.*^{20,24,32} performed this procedure with the assistance of an intervertebral disc endoscope without lamina injury, or exposing and pulling of the dural sac and nerve root. Zhou *et al.*³³ carried out the technology in China with micro-endoscopic assistance. Compared with the traditional TLIF, MIS-TLIF provides a higher magnification, a wider vision field, higher resolution images, and a safer and less complicated operation with small trauma, little bleeding, and better curative effect.

Clinical Outcome

Lower Blood Loss in ME-TLIF Surgery

In this study, we performed decompression and bone graft fusion surgery via the working sleeve of the METRx disc system without other supporting expandable sleeves. Its 18 mm diameter was smaller than all of the current expandable

channel diameters without the bottom expansion, so the paravertebral muscle stretch expansion can be significantly reduced. Compared with W-TLIF surgery, blood loss volume during or after surgery was significantly less in ME-TLIF surgery. No patients required blood transfusions during or after surgery. In addition, surgical recovery in the ME-TLIF group was faster than that in the W-TLIF group. The rehabilitation time of ambulation and the postoperative hospitalization duration were shorter, but there was no significant difference in hospitalization expenses.

VAS, ODI, and JOA Scores all Improved

Previous studies have shown that postoperative low back pain may be caused by excessive multifidus muscle check-point stripping, resulting in scarring of muscle fibers, decreased muscle function, poor back muscle function recovery after surgery,¹¹ and long hospitalization duration. Our study showed that the VAS (back and leg pain), ODI, and JOA scores of both groups were significantly improved compared with those before surgery, but the VAS of the back pain score for initial postoperative pain in the ME-TLIF group was lower than that in the W-TLIF group. Figures 5 and 6 show that after ME-TLIF surgery, the patient's symptoms were significantly relieved, and the VAS, ODI, and JOA scores were significantly improved, and adequate decompression of the nerve was confirmed by reexamination of the MRI.

Longer Radiation Exposure Time during ME-TLIF

In the present study, discectomy and placement of pedicle screws through a small tubular corridor led to more difficulty in the ME-TLIF surgical technique than in MIS-TLIF surgery. With the lack of proficiency in the operation and limited space for the operation, we needed to repeatedly confirm the screw position during surgery, resulting in an increase in intraoperative fluoroscopy time.³⁴ Bindal³⁵ did a prospective study about the time and dose of radiographic exposure during MIS-TLIF surgery. It showed that the mean fluoroscopy time was 1.69 min per case (a range of 0.82–3.73 min). However, the results of this study showed that the radiation exposure time was lower than that in Bindal's study. We also found that radiation exposure time in the ME-TLIF group was significantly higher than that in the W-TLIF group.

Smaller Incision with ME-TLIF

With the continuous development of minimally invasive spine surgery, micro-endoscopic discectomy (MED) is widely used as an extremely mature and minimally invasive technique. Isaacs firstly applied the combination of endoscopic discectomy and intervertebral fusion in TLIF surgery, which better protected the multifidus muscle, paravertebral muscles, and soft tissues. However, endoscopic microsurgery assisted by percutaneous MIS-TLIF surgery has higher technical requirements due to the limited diameter of the endoscopic working channel and the relatively small operating range.²⁵

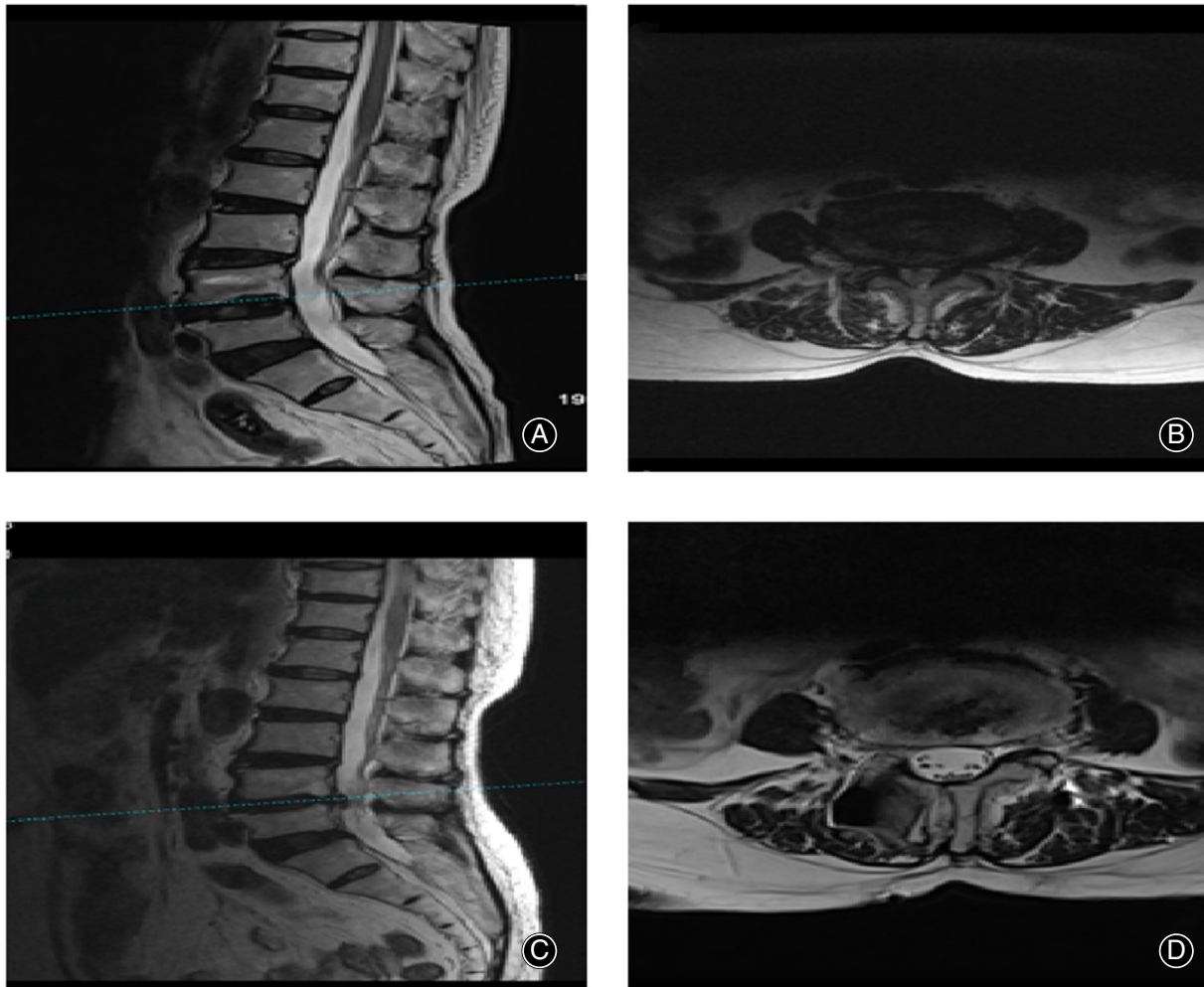


Fig. 5 A 70-year-old man admitted to our hospital after failing conservative treatment for lumbago and leg pain. (A) and (B) showed preoperative lumbar magnetic resonance imaging (MRI), showing herniated disc protruding posteriorly and significant narrowing of the intervertebral space. Preoperative MRI grading of Pfirrmann lumbar disc herniation was grade IV. (C) and (D) showed no disc herniation observed in the MRI of the lumbar spine 1 year after the microendoscopy-assisted transforaminal lumbar interbody fusion surgery, the height of the intervertebral space was restored, and the symptoms of lumbar and leg pain were relieved.

The minimally invasive surgery protected the multifidus muscle and other paravertebral muscles through expansion of the working channel.²⁵ ME-TLIF was able to minimize iatrogenic soft tissue and muscle injuries around the spine. In the ME-TLIF group, we only notched four 1 cm incisions to expand the paravertebral muscles. In contrast, W-TLIF surgery requires a large midline incision and long-term muscle distraction through the retractor. Thus, most of the patients in the ME-TLIF group started rehabilitating earlier, recovered sooner, and had a shorter hospitalization duration. When comparing the fusion of two groups, there was no significant difference between the two groups when followed up to 1 year. A representative case of interbody fusion 1 year after ME-TLIF surgery is shown in Figure 7.

No Perioperative Complications in ME-TLIF

In the present study, none of the patients in the ME-TLIF group had perioperative complications. In contrast, one urinary tract infection, one incision infection, and one wrong placement of a screw occurred in the W-TLIF group. The reported rate of complications varied between 9.5% and 52% for the W-TLIF procedure and between 0.6% and 31.6% for MIS-TLIF.³⁶ Due to the small sample size, postoperative complications were not formally accepted as a part of this study.

Technical Advantages and Experience

Advantages: (1) compared with W-TLIF, ME-TLIF better protects paravertebral muscles (because the incision is smaller and the stripping range is more limited);

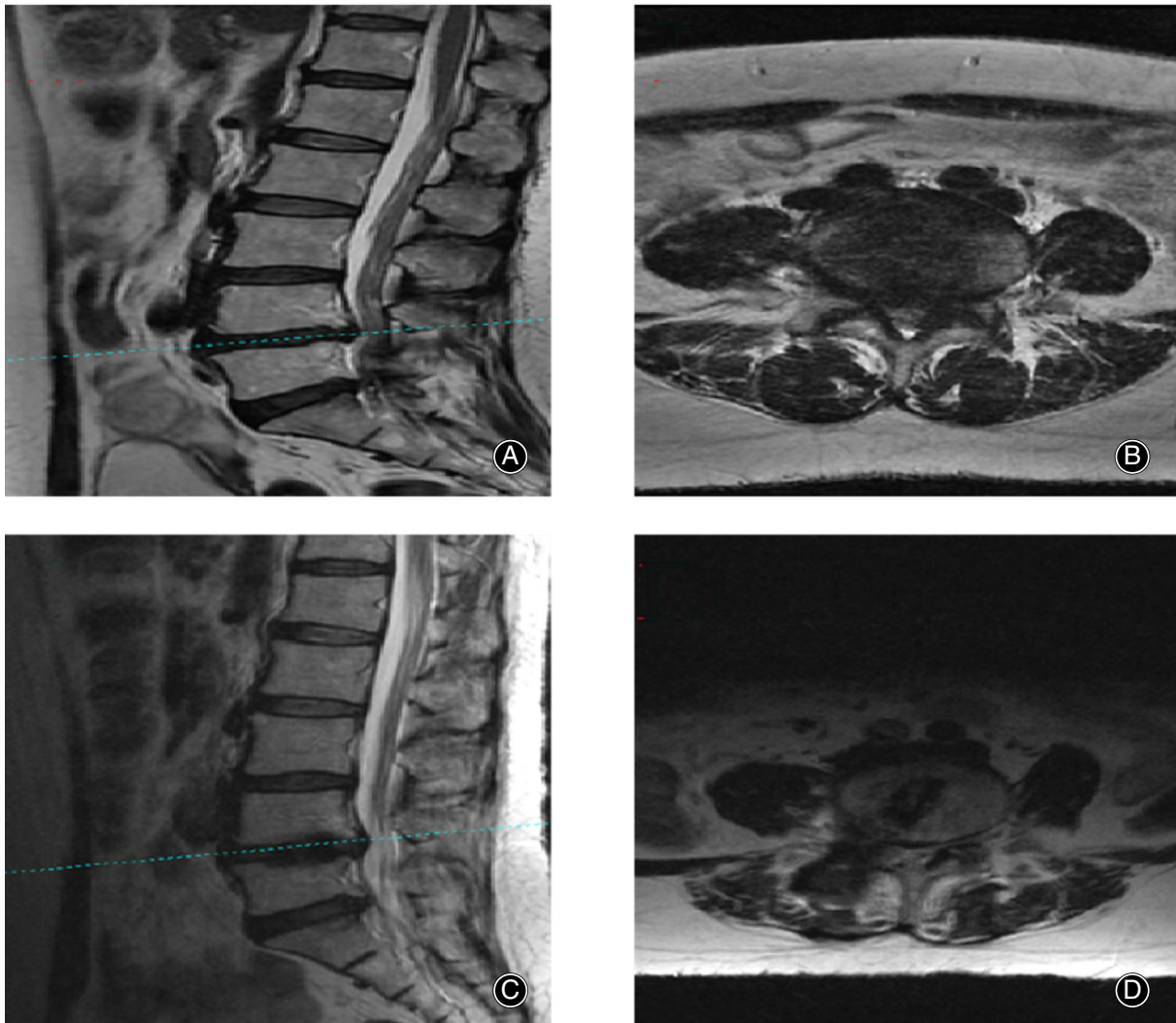


Fig. 6 A 57-year-old woman admitted to our hospital after failing conservative treatment for lumbago and leg pain. (A) and (B) showed preoperative lumbar magnetic resonance imaging, showing herniated disc protruding posteriorly and significant narrowing of the intervertebral space. Preoperative MRI grading of Pfirrmann lumbar disc herniation was grade IV. (C) and (D) showed no disc herniation observed in the MR of the lumbar spine 1 year after the microendoscopy-assisted transforaminal lumbar interbody fusion surgery, the height of the intervertebral space was restored, and the symptoms of lumbar and leg pain were relieved.

(2) compared with W-TLIF, the bleeding volume of ME-TLIF is smaller. In addition to the smaller stripping range, it may be related to the placement of the working cannula that can compress muscle tissue and avoid blood leakage between muscles; (3) ME-TLIF has less drainage flow and early drainage and extraction time, which is conducive to the patient's recovery as soon as possible; and (4) there is less low back pain caused by intraoperative muscle stripping after ME-TLIF, and the patient goes to the ground earlier, which is also conducive to the patient's recovery as soon as possible.

Experience: (1) after placing the body position, try to use the perspective positioning of the G-arm and insert Kirschner wire to shorten the nail placement time. If there is

no G-arm, two C-arms can also be used to cross place fluoroscopy; (2) when placing the working channel, it is necessary to locate the main parts accurately; and (3) fluoroscopy may still be needed before dealing with the endplate because the previous decompression operation may have made the channel swing. It is necessary to confirm that the channel is parallel to the intervertebral space, so as to avoid endplate injury.

Limitation of ME-TLIF

Some limitations may not be ignored in this study. First, the sample size in this retrospective study was small, so further multicenter prospective studies with a larger sample size are

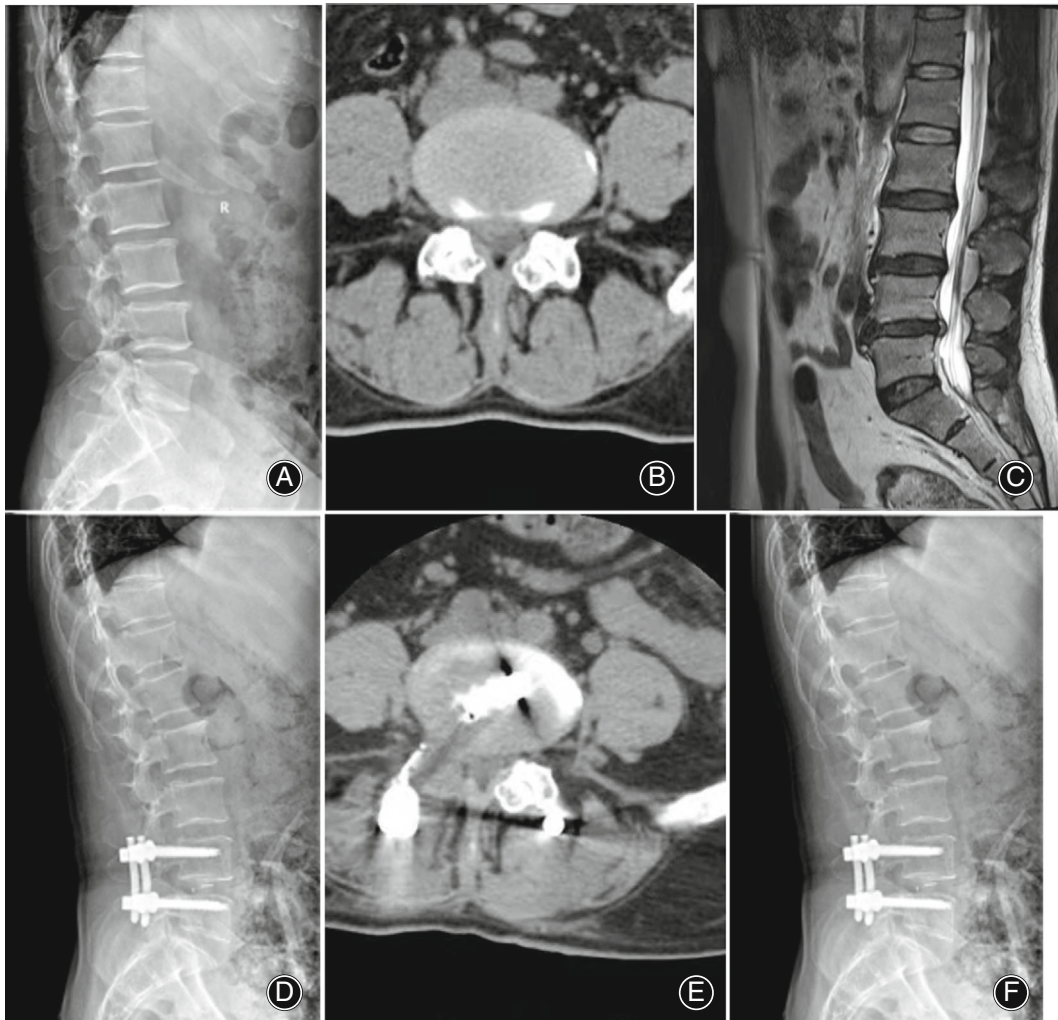


Fig. 7 A 51-year-old man, conservative treatment for low back pain was ineffective. (A)–(C): The preoperative image data of the patient showed degenerative disc disease in L4/L5 level. (D) and (E): Lateral radiograph and CT scan showing the internal fixation and cage the third day after microendoscopy-assisted transforaminal lumbar interbody fusion. (F): Lateral radiograph showing a solid fusion 1 year after surgery

required to confirm our results. Second, the inclusion criteria of patients in this study are not complete. Patients with multiple lumbar spinal canal stenosis and lumbar spondylolisthesis should be further studied in future research.

Conclusion

In summary, microendoscopy-assisted ME-TLIF provides patients with more beneficial perioperative clinical outcomes compared with W-TLIF. Despite the fact that both surgical methods improved fusion rates, ODI, and VAS, microendoscopy-assisted ME-TLIF is superior to W-TLIF in terms of less iatrogenic injury, less intraoperative or postoperative blood loss, and earlier rehabilitation. We will overcome the indiscriminate disadvantages of microendoscopy-assisted ME-TLIF on increased operative duration and radiologic exposure in the future. We also anticipate

that the difference in surgical time between the two groups will be gradually reduced.

Author Contributions

Designed and performed the experiments: Gang Chen, LongBiao Li, Wenge Liu, Jiandong Li. Collection and assembly of data: Gang Chen, LongBiao Li, Zhitao Shangguan, Zhenyu Wang. Data analysis: Gang Chen, LongBiao Li. Manuscript writing: All authors. Final approval of manuscript: All authors.

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Conflicts of Interest

The authors have no conflicts of interest to declare.

Ethics Statement

The experimental protocols were approved by Ethics Committee of Fujian Medical University Union Hospital (reference number: 2020KY0016).

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