

Clinical efficacy and safety of electronic flexible endoscope-assisted minimally invasive-transforaminal lumbar interbody fusion and conventional open transforaminal lumbar interbody fusion in the treatment of single-segment lumbar degenerative disease: a retrospective study

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Abstract

Objective

To compare the clinical efficacy and safety of electronic flexible endoscope-assisted non-expandable tubular minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) and conventional open transforaminal lumbar interbody fusion (TLIF) for treating single-level lumbar degenerative disease.

Methods

This study included 76 patients with single-level lumbar degenerative disease who underwent surgical treatment between January 2024 and December 2025. The patients were divided into the flexible endoscope-assisted MIS-TLIF group (MIS-TLIF group) ($n = 40$) and the TLIF group ($n = 36$). Pre-operative and post-operative (1, 3, 6, and 12 months) assessments included the Visual Analogue Scale (VAS) for low back pain and leg pain, the Oswestry Disability Index (ODI), and the MacNab criteria.

Results

The MIS-TLIF group had significantly longer operative and fluoroscopy times but less intraoperative blood loss and a shorter hospital stay than the TLIF group ($P < 0.05$). No significant differences in the rates of complications, fusion, or MacNab success were found between the two groups. At 1 and 3 months post-operatively, the MIS-TLIF group showed significantly lower VAS scores for low back pain and ODI scores than the TLIF group ($P < 0.05$). At 6 and 12 months, the MIS-TLIF group showed lower VAS scores for low back pain than the open TLIF group. No significant difference in VAS scores for leg pain was observed between the two groups at each post-operative time point.

Conclusions

Flexible endoscope-assisted MIS-TLIF for lumbar degenerative disease achieves clinical outcomes comparable to those of open TLIF. This technique offers advantages including less paraspinal muscle stripping, reduced intraoperative blood loss, and faster early post-operative recovery. Nevertheless, this technique is associated with a longer operative time, increased intraoperative fluoroscopy exposure, and a steep learning curve.

Introduction

Lumbar degenerative disease is a common condition in spine surgery, encompassing lumbar disc herniation, lumbar spinal stenosis, degenerative lumbar spondylolisthesis, degenerative lumbar scoliosis, and other subtypes. With the acceleration of population aging, the incidence of this disease has been rising steadily, considerably impairing patients' quality of life [1–3]. In patients who fail to respond to

adequate conservative management, surgery remains an effective intervention for improving clinical outcomes.

Transforaminal lumbar interbody fusion (TLIF), first described by Harms and Rolinger in 1982, is an established and effective surgical procedure for various lumbar degenerative conditions [4, 5]. TLIF involves less retraction of the dural sac and nerve roots than posterior lumbar interbody fusion (PLIF). However, the exposure required for conventional open TLIF necessitates extensive stripping of the paraspinal muscles and soft tissues, which can lead to paraspinal muscle atrophy and denervation. This approach is extremely likely to cause long-term low back pain and lumbar spine dysfunction after surgery [6]. Minimally invasive spine surgery has generally evolved along three trajectories: tubular retractor-based surgery, endoscopic surgery, and interventional procedures. The refinement of TLIF techniques and instrumentation has followed a similar direction. To mitigate the irreversible injury caused by stripping paraspinal muscles from the spinous processes and laminae, minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) has emerged in response to these challenges. While preserving the advantage of direct decompression offered by TLIF, MIS-TLIF uses specialised dilating retractors to access the target segment through natural intermuscular planes, thereby reducing soft tissue disruption and paraspinal muscle injury, accelerating post-operative functional recovery, and achieving reduced intraoperative blood loss and a shortened hospital stay [7]. Currently, MIS-TLIF is typically performed under direct visualisation by a tubular retractor. With direct visualisation, surgeons often prefer expandable retractors, which provide a larger working space and have a lower technical difficulty. However, the use of expandable retractors inevitably exerts substantial mechanical compression on the surrounding musculature. To prevent muscle from encroaching into the centre of the expandable channel, a greater amount of muscle and soft tissue than necessary is often deliberately resected. Moreover, even with direct visualisation, the retractor may partially obstruct the surgeon's view during decompression, leaving blind spots [8].

To address the above-mentioned limitations, we designed and introduced an electronic flexible endoscope system to refine the instrumentation and technical workflow of MIS-TLIF. This electronic flexible endoscope differs from the currently dominant rigid, water-medium endoscopic systems, such as percutaneous endoscopic lumbar discectomy and unilateral biportal endoscopy. Instead, our system is a flexible, air-medium endoscopic system. The flexible endoscope facilitates a smaller instrument profile and enhanced surgical precision. When combined with a set of non-expandable tubular retractors and an instrument support arm, this endoscope allows procedures, such as decompression and cage implantation, to be performed through a small paramedian incision via the Wiltse approach. The integrated electronic flexible endoscope system, together with its matched imaging equipment and minimally invasive surgical platform, has been preliminarily applied in anterior cervical decompression surgery with favourable clinical outcomes [9, 10]. In this study, we innovatively applied the electronic flexible endoscope with a non-expandable tubular retractor system to assist MIS-TLIF and compared it with conventional open TLIF. We aimed to verify the clinical efficacy and safety of flexible endoscope-assisted MIS-TLIF for single-level lumbar degenerative disease.

Materials and methods

Patients

We retrospectively reviewed 76 patients surgically treated for lumbar degenerative disease from January 2024 to December 2025. The Institutional Review Board of Hangzhou First People's Hospital approved this retrospective cohort study. Written informed consent was obtained from all patients. According to the surgical method, the patients were divided into two groups: those with flexible endoscope-assisted MIS-TLIF (MIS-TLIF group, $n = 40$) and those with conventional open TLIF (TLIF group, $n = 36$). The MIS-TLIF group comprised 24 men and 16 women, with a mean age of 56.90 ± 8.65 years. The TLIF group comprised 19 men and 17 women, with a mean age of 58.69 ± 9.11 years. The lumbar degenerative levels were L3/4 in 3 patients, L4/5 in 47 patients, and L5/S1 in 26 patients (Table 1).

Inclusion and exclusion criteria

The inclusion criteria included persistent radicular symptoms or neurogenic claudication consistent with the affected segment, no major relief or progressive worsening of symptoms after standardised conservative treatment for more than 3 months, and post-operative follow-up exceeding 1 year with complete clinical and follow-up records. Additionally, imaging studies (X-ray, computed tomography [CT], and magnetic resonance imaging) confirming a single-level lesion had to meet at least one of the following criteria: lumbar disc herniation; Meyerding grade I or II lumbar spondylolisthesis; and lumbar spinal stenosis or foraminal stenosis.

The exclusion criteria were as follows: previous lumbar spine surgery; discrepancy between imaging findings and clinical symptoms or signs; obvious degenerative lumbar scoliosis; severe lumbar spinal stenosis or gross instability, or spondylolisthesis greater than grade II; multi-level lumbar degenerative changes; severe comorbidities precluding surgery; a concurrent tumour, infection, or severe osteoporosis contraindicating internal fixation; and inability or unwillingness to comply with strict post-operative follow-up.

Novel electronic flexible endoscopic spine surgical system and instruments

The flexible endoscope-assisted non-expandable tubular system consists of a flexible endoscopic lens, soft tissue dilators, a series of non-expandable tubular channels, a freely adjustable locking arm, an integrated light source and imaging system, and a monitor. The flexible endoscope lens (developed and supplied by Guangzhou Minjun Medical Technology Development Co., Ltd.; China Invention Patent: CN116983066A) had a length of 20–40 mm, field-of-view angle of 0° – 30° (a 20° lens is commonly used in lumbar surgery; Fig. 1), diameter of 1.8 mm, and magnification of approximately 10–20 $\times$. The fixed channels were routinely available in two lengths of 55 mm and 75 mm. The diameters ranged from 10 to

22 mm in 2-mm increments for each length, with seven channels per length series. Regarding posterior lumbar fusion surgery, a channel diameter of 18–22 mm was recommended; all other instruments were the same as those for conventional open lumbar surgery.

Surgical methods

MIS-TLIF group

After anaesthesia, the patients were placed in the prone position. Under C-arm fluoroscopy, the surface projections of the pedicles above and below the target segment were identified. After routine skin preparation and draping, a 2-cm skin incision was made approximately 2.5 cm lateral to the midline on the affected side. The paraspinal muscles were bluntly dissected with a finger, and sequential dilators were inserted to gradually expand the channel to a diameter of 18–22 mm. A flexible endoscopic working channel was then mounted, secured, and locked with a supporting arm. Fluoroscopy was repeated to confirm that the working sleeve was positioned at the level of the target segment. The ideal channel position was maintained with an outward inclination of approximately 10°–20°, and the working channel was kept as horizontal as possible and directed toward the centre of the intervertebral space to facilitate subsequent cage insertion. A flexible endoscopic optical fibre was inserted, and the light source brightness, depth of field, and viewing angle were adjusted appropriately. Under endoscopic monitoring, the facet joints and lamina were exposed. The inferior articular process and part of the superior articular process were resected, and the hypertrophic ligamentum flavum was removed. The nerve root was explored and protected, and the nerve root canal and foraminal entrance were enlarged until a clearly pulsating dural sac was visible under the endoscope. In patients with spinal stenosis, decompression was performed, and the contralateral nerve root was explored when necessary. The ipsilateral traversing nerve root was retracted, the annulus fibrosus was incised, the degenerated nucleus pulposus was removed, and the cartilaginous endplates were curetted. The autologous bone harvested during the procedure was cut into bone chips and packed into the intervertebral space and into an appropriately sized cage, which was then inserted. The imaging data of the decompression process were saved. The flexible endoscopic optical fibre and working channel were removed. Percutaneous pedicle screws were placed bilaterally into the pedicles of the vertebrae above and below the target segment. The distance between the screw heads on each side was estimated, and the rod was pre-bent and then installed. After a satisfactory cage position was confirmed by fluoroscopy, thorough haemostasis was achieved, and the wound was irrigated with normal saline. A drainage tube was placed, and the wound was closed in layers.

TLIF group

The patients were placed in the prone position. The target segment was identified under C-arm fluoroscopy. After routine skin preparation and draping, a posterior midline longitudinal incision approximately 8–10 cm in length was made. The skin, subcutaneous tissue, and deep fascia were incised layer by layer. The paraspinal muscles and soft tissues were stripped laterally along the spinous

processes to fully expose the laminae and facet joints. Under fluoroscopic guidance, four pedicle screws were inserted. Part of the inferior articular process and the superior articular process on the affected side were resected, and the ligamentum flavum was removed to expose the intervertebral disc. The annulus fibrosus was incised, and the degenerated nucleus pulposus was removed. The nerve root was explored and protected; if necessary, decompression was performed and the contralateral nerve root was explored. The intervertebral space and cartilaginous endplates were prepared in an open fashion. The disc space was appropriately distracted using a trial sizer. Autologous bone harvested from the articular processes and lamina was trimmed, an appropriate amount of bone graft was placed into the disc space, and an appropriately sized cage filled with the above-mentioned autologous bone was inserted. The distance between the screw heads on each side was estimated, and the rod was pre-bent and then installed. Optional appropriate compression was applied on the affected side. After satisfactory positioning of the cage and confirmation by fluoroscopy of the pedicle screw–rod construct, haemostasis was checked, the wound was irrigated with normal saline, a drainage tube was placed, and the wound was closed in layers.

Post-operative treatment

Post-operatively, routine prophylactic antibiotics were administered. Depending on the patient's condition, dehydrating agents, corticosteroids, and neurotrophic drugs were used as needed to reduce nerve root oedema, and oral nonsteroidal anti-inflammatory drugs were prescribed as appropriate for pain relief. The drainage tube was typically removed 24–48 hours after surgery. In the MIS-TLIF group, the patients were allowed moderate ambulation with a brace 3 days post-operatively, whereas in the TLIF group, bed rest could be extended as clinically indicated. After discharge, all patients were required to wear a lumbar brace for 8 weeks. Pre-operative and post-operative clinical data were recorded, and the patients were instructed to attend regular follow-up visits at 1, 3, 6, and 12 months post-operatively, at which time imaging studies were performed.

Efficacy assessment

The operative time, intraoperative blood loss, length of hospital stay, post-operative complications, visual analogue scale (VAS) scores for low back and leg pain, and Oswestry Disability Index (ODI) scores were recorded and compared between the two groups. VAS and ODI scores were assessed pre-operatively and at 1, 3, 6, and 12 months post-operatively. Higher VAS scores (0–10) indicate more severe pain, and higher ODI scores (0–50) indicate more severe disability. At the final follow-up at 1 year post-operatively, clinical efficacy was evaluated using the Macnab criteria and classified as excellent, good, fair, or poor. Excellent and good outcomes were defined as treatment success, and the success rate was assessed. At the same follow-up, the fusion rate was assessed using lumbar flexion–extension radiographs or lumbar CT scans. All imaging data were independently evaluated by two spine surgeons. In cases of disagreement, the fusion status was determined by discussion and consensus. Non-union on radiographs was defined as segmental motion $> 3^\circ$, a residual radiolucent zone, or the absence of

definitive bony bridging. Non-union on CT was defined as the presence of a gas sign, a residual radiolucent zone, or the absence of definitive bony bridging [11, 12].

Statistical analysis

All statistical analyses were performed using SPSS 25.0 software. Continuous data are presented as the mean $\pm$ standard deviation. Between-group comparisons of continuous variables were performed using the *t* test, and comparisons between multiple groups were performed using an analysis of variance. Categorical data were compared using the χ^2 test. $P < 0.05$ was considered statistically significant.

Results

Perioperative clinical information

All surgical procedures were completed successfully, and all procedures in both groups were performed by the same orthopaedic surgical team. An analysis of perioperative data showed that the operative time was significantly longer in the MIS-TLIF group than in the TLIF group ($P < 0.05$), and the fluoroscopy time was significantly longer in the MIS-TLIF group than in the TLIF group ($P < 0.05$). However, intraoperative blood loss was significantly lower in the MIS-TLIF group than in the TLIF group ($P < 0.05$), and the hospital stay was significantly shorter in the MIS-TLIF group than in the TLIF group ($P < 0.05$) (Table 2).

Post-operative complications

The overall complication rate was 10.0% (4/40) in the MIS-TLIF group, including nerve injury in two cases, a dural tear in one case, and endplate injury in one case. The overall complication rate was 16.7% (6/36) in the TLIF group, including a dural tear in two cases, epidural haematoma in two cases, and nerve injury in one case. No retained nucleus pulposus or wound infection occurred in either group. There was no significant difference in the overall complication rate between the two groups (Table 3).

Clinical efficacy

All patients in both groups completed post-operative follow-up. The mean follow-up duration was 14.09 $\pm$ 1.08 months (range, 12–16 months). There were no significant differences in pre-operative low back pain VAS scores, leg pain VAS scores, ODI scores, or post-operative fusion rates between the two groups. Low back pain VAS, leg pain VAS, and ODI scores at 1, 3, 6, and 12 months post-operatively were significantly lower than those pre-operatively in both groups ($P < 0.05$). This finding indicated that both procedures achieved significant efficacy for single-level lumbar degenerative disease. At 1 and 3 months post-operatively, the MIS-TLIF group had significantly lower low back pain VAS and ODI scores than the TLIF group ($P < 0.05$). At 6 and 12 months post-operatively, no significant differences in low back pain, VAS, or ODI scores were observed between the two groups. At all post-operative time points, there was no significant difference in leg pain VAS scores between the two groups. These findings indicated that flexible endoscope-assisted MIS-TLIF provided a greater advantage in early post-operative functional recovery, whereas the mid-term outcomes of the two groups tended to be similar. At the final follow-up,

the fusion rate was 100% (40/40) in the MIS-TLIF group and 100% (36/36) in the TLIF group, with no significant difference between the groups. According to the modified Macnab criteria at 1 year post-operatively, the satisfaction rate was 92.5% in the MIS-TLIF group (excellent in 31, good in 6, fair in 3) and 91.7% in the TLIF group (excellent in 26, good in 7, fair in 3), with no significant difference between the groups (Table 4).

Discussion

Lumbar degenerative disease is one of the most common conditions encountered in spine surgery, primarily encompassing lumbar disc herniation, lumbar spinal stenosis, and degenerative lumbar spondylolisthesis. This disease is a major cause of low back pain, radicular pain, and neurogenic claudication. Conventional posterior open fusion procedures, such as PLIF and the various TLIF techniques derived from it, can effectively achieve neural decompression and symptom relief. PLIF was first introduced by Cloward et al. in 1943 [13], and TLIF was initially described by Harms and Rolinger in 1982 [4]. To minimise intraoperative injury and reduce post-operative complications, the surgical treatment of lumbar degenerative disease has gradually evolved from conventional open procedures to minimally invasive approaches. TLIF has the advantage of requiring less retraction of the dural sac and nerve roots and is associated with faster post-operative recovery than PLIF. However, open TLIF is also performed via a posterior midline approach, which inevitably results in extensive stripping and injury to the paraspinal muscles, and is an important contributor to post-operative axial lumbar pain and lumbar functional disability [14, 15]. TLIF procedures use a transforaminal approach, which is not limited to a posterior or paramedian approach but also includes access through the foraminal zone. Recent anatomical studies on the Kambin's triangle concept have proposed that if "Kambin's triangle" is understood as a three-dimensional triangular prism space (Kambin's prism), a new classification of the transforaminal approach can be established, and tubular and endoscopic fusion techniques can be better unified under the TLIF category [16]. Minimally invasive techniques have consistently been an important direction in spine surgery. On the premise of safety, minimal invasiveness, and enhanced recovery, our study investigated how to modify instruments and techniques based on the TLIF procedure to further improve surgical outcomes and patients' satisfaction.

Since Foley et al. [17] introduced the MIS-TLIF technique, after continuous refinement and exploration, it has become a tubular minimally invasive procedure that effectively replaces open surgery. The classic MIS-TLIF procedure is performed by a paramedian intermuscular approach using an expandable tubular retractor. Under the retractor, surgical steps including exposure, decompression, bone grafting, and cage placement, are completed sequentially. The midline posterior attachments to the spinous processes are largely preserved, and stripping and exposure of the paraspinal soft tissues are reduced to a certain extent, making it a representative form of tubular minimally invasive spine surgery. In recent years, advances in optical imaging technology and improvements in endoscopic materials and instruments have driven the rapid development of spinal endoscopic techniques. An example of this advancement is that transforaminal endoscopic techniques allow precise decompression under water-based visualisation. The advantages of these techniques lie not only in performing simple discectomy for

lumbar disc herniation but also in enabling endoscopic fusion procedures. Osman et al. first reported an endoscopic transforaminal decompression and fusion procedure combined with percutaneous pedicle screw fixation for the lumbar spine in 2012, namely Endo-TLIF [18]. We previously conducted a retrospective case comparison between transforaminal lateral-approach endoscopic fusion and expandable tubular MIS-TLIF [19]. We found that although transforaminal endoscopic instruments can perform endoscopic fusion, the efficiency of decompression under the endoscope is low, and the exiting nerve root is particularly vulnerable to injury and compression during cage insertion. The unilateral biportal endoscopic technique overcomes the limitations of a single-channel transforaminal endoscope, such as a narrow field of vision and limited working space, and enables posterior-approach endoscopic fusion. However, the unilateral biportal endoscopic technique requires experience in arthroscopic surgery and has a longer learning curve [20, 21]. Unlike percutaneous endoscopic lumbar discectomy and unilateral biportal endoscopy, MED operates in an air medium. With the increasing use of water-medium endoscopes, air-medium endoscopy appears to have gradually fallen out of favour. In fact, as early as the beginning of this century, Xifeng Zhang, Wenjun Wang, and others achieved preliminary success in MED-assisted implantations of expandable cages [22, 23]. Since this time, the exploration of air-medium endoscopic techniques has not ceased.

MIS-TLIF procedures can be divided into expandable channels and fixed channels according to the surgical channel used. Expandable channels compress the surrounding soft tissues, causing excessive soft-tissue encroachment into the channel and increasing the amount of muscle that must be dissected and resected. A larger exposure also implies a greater risk of resecting excess bony structures. In less experienced surgeons, the use of an expandable channel may lead to decompression beyond what is actually required. In theory, the non-expandable channel system can reduce soft-tissue compression and retraction. The embracing effect of the surrounding soft tissues also enhances instrument stability. Correspondingly, it may reduce soft-tissue dissection within the channel and limit the extent of facet joint and lamina resection. However, the linear working space created by the tubular channel restricts the manipulation angle of the instruments and the field of visualisation. Moreover, a non-expandable channel system often requires an excellent light source and an endoscopic system. Wu et al. [24] compared endoscope-assisted fixed channels with conventional expandable retractor systems in MIS-TLIF and found that both achieved comparable clinical efficacy and fusion rates. However, the endoscope-assisted fixed channel showed certain advantages in terms of post-operative drainage volume and analgesic use rate. Nevertheless, the endoscopes used in the above-mentioned studies were mostly rigid instruments, with their viewing axis essentially aligned with the longitudinal axis of the working channel. The ability to adjust the observation angle is limited, and when managing lateral or deep structures, adjusting the channel or patient's position is necessary to complete the procedure.

The electronic flexible endoscope and MED belong to the category of air-medium endoscopy. Compared with conventional rigid endoscopes, the technological advantages of the electronic flexible endoscope are evident in several dimensions. Regarding imaging principles, traditional optical endoscopes rely on a system of prisms and lenses to transmit images and are connected to an external cold light source and camera, resulting in considerable overall weight, limited manoeuvrability, and potential concerns

associated with repeated use, such as inadequate sterilisation and mechanical failure [25]. By contrast, the electronic flexible endoscope integrates a image sensor and an LED cold light source at its tip, and the image is transmitted directly to the display terminal as a digital signal. This approach eliminates the bulky optical relay system and greatly reduces the weight of the endoscope body. Regarding the field of view, the tip of the electronic flexible endoscope can be bent at an angle, enabling visualisation outside the straight line of sight. When addressing the contralateral recess of the intervertebral space and posterior vertebral body osteophytes, the flexible endoscope can effectively reduce dependence on the channel angle, which is a degree of operational freedom that is difficult to achieve with conventional rigid endoscopes. Regarding the working space, the slender body of the flexible endoscope resembles a “cable” that can be bent arbitrarily, occupying a smaller cross-sectional area of the channel and leaving more room for the manipulation of instruments, thereby reducing the likelihood of “instrument crowding.” These characteristics are unique advantages that make the flexible endoscope more readily adaptable for integration into a fixed-channel MIS-TLIF surgical system. To date, this technology has been preliminarily applied in anterior cervical fusion, and clinical reports have shown its potential advantages in reducing intraoperative blood loss and accelerating post-operative recovery [9, 10].

In this study, we retrospectively analysed a series of patients with single-level lumbar degenerative disease treated with flexible endoscope-assisted MIS-TLIF and compared them with a cohort of patients who underwent open TLIF. Peri-operative parameters showed that the operative time was longer in the MIS-TLIF group than in the TLIF group. However, intraoperative blood loss was less and the length of hospital stay was shorter in the MIS-TLIF group than in the TLIF group. This finding can be attributed to the small minimally invasive incision and the high-definition magnified view provided by the flexible endoscope, which facilitates precise haemostasis. Less blood loss together with less surgical trauma promotes enhanced post-operative recovery and consequently shortens the hospital stay. Regarding clinical efficacy, at 1 and 3 months post-operatively, the low back pain VAS and ODI scores in the MIS-TLIF group were significantly better than those in the TLIF group. At 6 and 12 months post-operatively, although the differences in low back pain VAS and ODI scores between the two groups were not significant, low back pain VAS scores in the MIS-TLIF group were consistently lower than those in the TLIF group. At all post-operative time points, no significant difference in leg pain VAS scores was observed between the groups. These findings indicate that the flexible endoscope-assisted technique offers advantages in relieving early low back pain and accelerating functional recovery, which may be associated with less paraspinal muscle injury and a milder inflammatory response. At 1 year post-operatively, the Macnab excellent and good rates were similar between the two groups. In summary, flexible endoscope-assisted MIS-TLIF demonstrates a clear advantage in early recovery, and its mid- to long-term efficacy is comparable to that of open TLIF.

Regarding post-operative complications in this study, the complication profile of flexible endoscope-assisted MIS-TLIF was essentially consistent with that of conventional MIS-TLIF, and no specific complications related to the flexible endoscope were observed. In this study, the overall complication rate was not significantly different between the groups. These rates are consistent with the complication rates during the learning curve period for MIS-TLIF reported in the literature (6.8%–23.8%) [26]. A dural

tear occurred in both groups. There are several possible causes of this tear. In the MIS-TLIF group, the dural tear may have been related to adhesions of the ligamentum flavum, restricted manipulation angles under the working channel, and contact between instruments and the dura. In the TLIF group, this tear may have been caused by traction injury when separating severe adhesions between the ligamentum flavum and the dural sac by the open approach. Nerve injury occurred in both groups, and all cases manifested as transient nerve root dysfunction. Complete recovery was achieved within 3 months post-operatively, with no permanent neurological deficits. Epidural haematoma was only observed in the TLIF group and was attributed to the extensive paraspinal muscle stripping associated with open surgery, increased wound oozing, and inadequate post-operative drainage. Both cases resolved with conservative management. One case of endplate injury occurred in the flexible endoscope group. This finding may have been related to the narrow working channel and insertion of the cage in a direction non-parallel to the endplate, leading to accidental endplate damage. However, non-union and cage subsidence were not observed post-operatively. In the TLIF group, there was one case of delayed wound healing due to subcutaneous fat liquefaction, which healed by secondary intention after dressing changes. No wound infection occurred in either group. In fact, flexible endoscope-assisted MIS-TLIF is performed via the paraspinal approach, which compared with the midline incision used in open fusion surgery, is more conducive to wound healing. However, this advantage was not observed in this study. Regarding the fusion rate, all operated lumbar segments in both groups achieved solid fusion, and there was no significant difference between the two groups. This finding indicates that the air-medium endoscopic technique does not compromise cage placement or the fusion rate.

The flexible endoscope-assisted MIS-TLIF procedure still has several limitations. First, in some severe lumbar degenerative diseases, such as severe spinal stenosis, grade II or greater spondylolisthesis, and degenerative scoliosis, achieving adequate decompression under endoscopic visualisation is difficult. Inserting a cage through the channel and under the endoscope is challenging, and the reduction and correction achieved with percutaneous pedicle screw fixation and decompression are limited. Second, compared with conventional open TLIF and expandable-channel MIS-TLIF, the working space in flexible endoscope-assisted fusion surgery is smaller, there tends to be more bleeding within the endoscopic field, the endoscope lens is easily contaminated, and the procedural difficulty increases substantially. These factors require considerable skills in channel-based and endoscopic manipulation and entail a relatively long learning curve. Third, the electronic flexible endoscope is a consumable device. Intraoperative collisions and abrasions due to instrument insertion and withdrawal can impair the imaging quality of this device. If this type of endoscope is used as a single-use disposable item, the surgical cost for the patient will increase. Finally, while the conventional view is that MIS-TLIF is not suitable for lesions involving more than three segments or spondylolisthesis greater than grade II, we believe that even more careful patient selection is required for flexible endoscope-assisted fixed-channel surgery. Additionally, cases should be selected cautiously when first adopting this technique.

Our study showed the early and mid-term clinical efficacy and the advantages and disadvantages of flexible endoscope-assisted MIS-TLIF and TLIF for treating lumbar degenerative disease, providing original clinical insights. However, there are several limitations to this study. This was a single-centre

retrospective study with a limited sample size, and inevitably selection bias may have been present during case screening. Furthermore, parameters such as the operative time and fluoroscopy time for the novel flexible endoscopic fusion procedure were affected by the learning curve associated with early cases, resulting in substantial data dispersion. Additionally, the follow-up duration in this study was relatively short, and further follow-up is required to compare the long-term outcomes between the two groups to validate the long-term efficacy and safety of flexible endoscope-assisted MIS-TLIF.

Conclusion

Flexible endoscope-assisted MIS-TLIF for single-level lumbar degenerative disease can achieve mid- to long-term efficacy comparable to that of open TLIF. Furthermore, this technique offers advantages in reducing intraoperative blood loss, shortening the hospital stay, and accelerating early recovery, thereby facilitating early post-operative recovery. However, the indications for flexible endoscope-assisted MIS-TLIF are relatively limited, the learning curve is long, and surgeons need to strictly select patients according to the indications.

Data are presented as mean $\pm$ standard deviation or number of cases. $P > 0.05$ was considered no statistically significant.

Data are presented as mean $\pm$ standard deviation. The fusion rate is expressed as a percentage (number of fused segments / total segments). $P < 0.05$ was considered statistically significant.

Data are presented as the number of cases. Some patients may have experienced more than one complication. $P > 0.05$ was considered no statistically significant.

Schematic diagram of the electronic flexible endoscope (a). Display monitor (b). Surgical dilation channels with different diameter gradients and lengths (c).

Typical case 1. A 73-year-old man presented with low back pain and left lower limb pain and numbness for 1 year, which had aggravated over the past month. Sagittal MRI (a) and axial MRI (b) demonstrated a massive L5/S1 disc extrusion. Lateral flexion-extension radiographs showed severe disc space narrowing, although the intervertebral segment remained stable (d). Cage implantation under the electronic flexible endoscope and fixed channel. Intraoperative fluoroscopy showed satisfactory cage position with a slight increase in disc space height (e, f). Retraction of the S1 traveling nerve root and cage implantation under the flexible endoscope, with satisfactory decompression of the dural sac and traveling nerve root (g,h). Wound closure (i). Anteroposterior and lateral X-ray one month after surgery (j, k). Lateral X-ray six month after surgery (l).

Typical case 2. A 39-year-old woman presented with low back pain and left lower limb pain for over 7 years, which had aggravated over the past 2 months. Sagittal MRI revealed L5/S1 disc herniation with endplate inflammatory changes (a). Axial MRI revealed L5/S1 disc herniation (b). Sagittal CT revealed severe L5/S1 disc space narrowing with endplate osteochondritis (c). Preoperative incision planning (d).

Channel fixation and establishment of the surgical field under the flexible endoscope (e). Cage placement confirmed by intraoperative fluoroscopy (f, g). Under the flexible endoscopic view, the dural sac and traversing nerve root were clearly visualized; small arterial pulsations were visible on the surface of the dural sac, and the cage could be seen after retracting the nerve root. (h, i). Anteroposterior and lateral X-ray one month after surgery (j, k). Lateral X-ray six month after surgery (l).

Typical case 3. A 76-year-old man presented with low back pain and left lower limb pain and numbness for 2 years, which had aggravated over the past 1 month. Sagittal MRI revealed L4/L5 disc herniation and spondylolisthesis (a). Axial MRI revealed L4/L5 disc herniation (b). Flexion-extension radiographs revealed L4/L5 segmental instability (c, d). After cage implantation, the dural sac and L5 nerve root were clearly visualized under the flexible endoscope, and the decompression was deemed satisfactory. (e). Intraoperative fluoroscopy confirmed the positions of the cage (f, g). Wound closure (h). Anteroposterior and lateral X-ray one month after surgery (i, j). Anteroposterior and lateral X-ray six month after surgery (k, l).

Abbreviations

MIS-TLF

minimally invasive transforaminal lumbar interbody fusion

TLIF

transforaminal lumbar interbody fusion

VAS

visual analogue scale

ODI

Oswestry Disability Index

PLIF

Posterior lumbar interbody fusion

MED

Microendoscopic Discectomy

Declarations

Ethics approval and consent to participate

This study was in accordance with the Declaration of Helsinki. This study was approved by the Ethics Review Board of Hangzhou First People's Hospital, Hangzhou, China. We obtained all necessary consent from all patients involved in the study, including informed consent to participate in the study where appropriate. Clinical trial number: not applicable.

Consent for publication

Written informed consent for publication of their clinical details and/or clinical images was obtained from all study patients. Written informed consent for publication of their clinical details and/or clinical images was obtained from all study patients.

Availability of data and materials

All data generated by the study and analysed are included in this article.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Xingyu Gao and Yakoub Othman Daud wrote the manuscript. Xingyu Gao, Yakoub Othman Daud and Xuepeng Wang contributed to the study design. Xingyu Gao, Yakoub Othman Daud and Zhengao Huang contributed to the data collection. Zhengbing Gu contributed to the statistical analysis. All authors have read and approved the final manuscript.

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References

1. Yasuhara T, Sasada S, Date I. [Lumbar Degenerative Disease:Key for Diagnosis]. No Shinkei Geka. 2021;49(6):1233–45.
2. Katz JN, Zimmerman ZE, Mass H, Makhni MC. Diagnosis and Management of Lumbar Spinal Stenosis: A Review. JAMA. 2022;327(17):1688–99.
3. Kim CH, Chung CK, Kim MJ, Choi Y, Kim MJ, Hahn S, Shin S, Jong JM, Lee JH. Increased Volume of Lumbar Surgeries for Herniated Intervertebral Disc Disease and Cost-Effectiveness Analysis: A Nationwide Cohort Study. Spine. 2018;43(8):585–93.
4. Harms J, Rolinger H. [A one-stager procedure in operative treatment of spondylolistheses: dorsal traction-reposition and anterior fusion (author's transl)]. Z Orthop Ihre Grenzgeb. 1982;120(3):343–7.
5. Drossopoulos PN, Ononogbu-Uche FC, Tabarestani TQ, Huang CC, Paturu M, Bardeesi A, Ray WZ, Shaffrey CI, Goodwin CR, Erickson M et al. Evolution of the Transforaminal Lumbar Interbody Fusion

- (TLIF): From Open to Percutaneous to Patient-Specific. *J Clin Med* 2024, 13(8).
6. Liu H, Li J, Sun Y, Wang X, Wang W, Guo L, Zhang F, Zhang P, Zhang W. A Comparative Study of a New Retractor-Assisted WILTSE TLIF, MIS-TLIF, and Traditional PLIF for Treatment of Single-Level Lumbar Degenerative Diseases. *Orthop Surg*. 2022;14(7):1317–30.
 7. An B, Ren B, Liu Y, Han Z, Wu J, Mao K, Liu J. Clinical efficacy and complications of MIS-TLIF and TLIF in the treatment of upper lumbar disc herniation: a comparative study. *J Orthop Surg Res*. 2024;19(1):317.
 8. Ge DH, Stekas ND, Varlotta CG, Fischer CR, Petrizzo A, Protopsaltis TS, Passias PG, Errico TJ, Buckland AJ. Comparative Analysis of Two Transforaminal Lumbar Interbody Fusion Techniques: Open TLIF Versus Wiltse MIS TLIF. *Spine*. 2019;44(9):E555–60.
 9. Zhao QH, Liu YH, Lin RZ, Zheng ZY, Liu ZC, Zhou XY, Fan CH, Li QC. Flexible endoscopic cervical minimally invasive system–assisted anterior cervical discectomy and fusion for two–level cervical spondylotic myelopathy. *Chin J Orthop*. 2025;45(1):37–43.
 10. Zhang BZ, Zhao QH, Mao WT, Jiang TB, Zheng ZY, Chen TY, Li QC, Liu ZC. Short-term efficacy of flexible endoscope-assisted single-level cervical artificial disc replacement for cervical spondylosis. *Chin J Spine Spinal Cord*. 2025;35(5):484–90.
 11. Cook SD, Patron LP, Christakis PM, Bailey KJ, Banta C, Glazer PA. Comparison of methods for determining the presence and extent of anterior lumbar interbody fusion. *Spine*. 2004;29(10):1118–23.
 12. Nakashima H, Yukawa Y, Ito K, Horie Y, Machino M, Kanbara S, Morita D, Imagama S, Ishiguro N, Kato F. Extension CT scan: its suitability for assessing fusion after posterior lumbar interbody fusion. *Eur Spine J*. 2011;20(9):1496–502.
 13. Cloward RB. The treatment of ruptured lumbar intervertebral discs by vertebral body fusion. I. Indications, operative technique, after care. *J Neurosurg*. 1953;10(2):154–68.
 14. Putzier M, Hartwig T, Hoff EK, Streitparth F, Strube P. Minimally invasive TLIF leads to increased muscle sparing of the multifidus muscle but not the longissimus muscle compared with conventional PLIF-a prospective randomized clinical trial. *Spine J*. 2016;16(7):811–9.
 15. Fu CJ, Chen WC, Lu ML, Cheng CH, Niu CC. Comparison of paraspinal muscle degeneration and decompression effect between conventional open and minimal invasive approaches for posterior lumbar spine surgery. *Sci Rep*. 2020;10(1):14635.
 16. Fanous AA, Tumialán LM, Wang MY. Kambin's triangle: definition and new classification schema. *J Neurosurg Spine*. 2020;32(3):390–8.
 17. Foley KT, Lefkowitz MA. Advances in minimally invasive spine surgery. *Clin Neurosurg*. 2002;49:499–517.
 18. Osman SG. Endoscopic transforaminal decompression, interbody fusion, and percutaneous pedicle screw implantation of the lumbar spine: A case series report. *Int J Spine Surg*. 2012;6:157–66.
 19. Chen H, Zheng G, Bian Z, Hou C, Li M, Zhang Z, Zhu L, Wang X. Comparison of minimally invasive transforaminal lumbar interbody fusion and endoscopic lumbar interbody fusion for lumbar

- degenerative diseases: a retrospective observational study. *J Orthop Surg Res.* 2023;18(1):389.
20. Peng J, Lin R, Fang D, He Z, Zhao Q, Li Q. Learning curve insights in Unilateral Biportal Endoscopic (UBE) spinal procedures: proficiency cutoffs and the impact on efficiency and complications. *Eur Spine J.* 2025;34(3):954–73.
21. Xu J, Wang D, Liu J, Zhu C, Bao J, Gao W, Zhang W, Pan H. Learning Curve and Complications of Unilateral Biportal Endoscopy: Cumulative Sum and Risk-Adjusted Cumulative Sum Analysis. *Neurospine.* 2022;19(3):792–804.
22. Zhang XF, Wang Y, Xiao SH, Liu ZS, Liu BW, Zhang YG. Feasibility and clinical application of percutaneous lateral approach endoscopic discectomy. *Chin J Spine Spinal Cord* 2006;(9):659–62.
23. Yao NZ, Wang WJ, Hu WK. Clinical analysis of microendoscopic discectomy for lumbar disc herniation: a report of 172 cases. *China J Endoscopy.* 2005;(1):55–6, 66.
24. Wu J, Zhang C, Lu K, Li C, Zhou Y. A Novel Inextensible Endoscopic Tube Versus Traditional Extensible Retractor System in Single-Level Minimally Invasive Transforaminal Lumbar Interbody Fusion: A Prospective Observation Study. *Pain Physician.* 2019;22(6):E587–99.
25. Cheng SH, Lin YT, Lu HT, Tsuei YC, Chu W, Chu WC. The Evolution of Spinal Endoscopy: Design and Image Analysis of a Single-Use Digital Endoscope Versus Traditional Optic Endoscope. *Bioeng (Basel)* 2024, 11(1).
26. Shuman WH, Baron RB, Neifert SN, Martini ML, Chapman EK, Schupper AJ, Caridi JM, Steinberger J. MIS-TLIF Procedure is Improving With Experience: Systematic Review of the Learning Curve Over the Last Decade. *Clin Spine Surg.* 2022;35(9):376–82.

Tables

Table 1. General information

	Flexible endoscope-assisted MIS-TLIF group	TLIF group	<i>P</i>
Sex (male : female)	24:16	19:17	0.531
Age (years)	56.90±9.19	58.69±9.11	0.396
Involved segment			0.861
L3/4	2	1	
L4/5	24	23	
L5/S1	14	12	
Diagnosis			0.703
Lumbar disc herniation	11	8	
Lumbar spondylolisthesis	10	12	
Lumbar spinal stenosis	19	16	

Data are presented as mean ± standard deviation or number of cases. *P* > 0.05 was considered no statistically significant.

Table 2. Perioperative data

	Flexible endoscope-assisted MIS-TLIF group	TLIF group	<i>P</i>
Operative time (min)	182.93±11.04	141.28±9.21	<0.001
Intraoperative blood loss (mL)	104.25±12.26	233.31±19.88	<0.001
Fluoroscopy time (s)	43.45±3.76	34.56±4.08	<0.001
Length of hospital stay (d)	5.58±0.68	8.69±0.62	<0.001
Postoperative fusion rate	100% (40/40)	100% (36/36)	1.000

Data are presented as mean ± standard deviation. The fusion rate is expressed as a percentage (number of fused segments / total segments). *P* < 0.05 was considered statistically significant.

Table 3. Complications

	Flexible endoscope-assisted MIS-TLIF group	TLIF group	<i>P</i>
Retained nucleus pulposus	0	0	0.604
Nerve injury	2	1	
Dural tear	1	2	
Endplate injury	1	0	
Epidural hematoma	0	2	
Infection	0	0	
Delayed wound healing	0	1	
Cage non-fusion	0	0	

Data are presented as the number of cases. Some patients may have experienced more than one complication. $P > 0.05$ was considered no statistically significant.

Table 4. Clinical efficacy			
	Flexible endoscope-assisted MIS-TLIF group	TLIF group	
VAS for low back pain			
Preoperative	6.48 ± 1.11	6.53 ± 1.21	0.843
One month after surgery	2.78 ± 0.80	3.50 ± 0.51	<0.001
Three month after surgery	2.63 ± 0.84	3.17 ± 0.78	0.005
Six month after surgery	1.68 ± 0.57	1.75 ± 0.55	0.564
One year after surgery	1.35 ± 0.48	1.33 ± 0.48	0.880
VAS for low leg pain			
Preoperative	5.93 ± 0.86	5.86 ± 0.87	0.748
One month after surgery	2.75 ± 0.81	3.03 ± 0.71	0.139
Three month after surgery	2.08 ± 0.92	1.97 ± 0.80	0.608
Six month after surgery	1.68 ± 0.53	1.53 ± 0.51	0.219
One year after surgery	1.35 ± 0.48	1.44 ± 0.50	0.407
ODI			
Preoperative	45.00 ± 2.94	44.44 ± 3.00	0.417
One month after surgery	18.75 ± 2.69	22.64 ± 3.82	<0.001
Three month after surgery	13.15 ± 2.62	14.78 ± 3.20	0.017
Six month after surgery	7.53 ± 1.39	6.94 ± 1.55	0.090
One year after surgery	6.33 ± 1.14	5.94 ± 1.07	0.139
MacNab			
One year after surgery	92.5%	91.7%	0.893
Data are presented as mean ± standard deviation. VAS, Visual Analogue Scale (0–10); ODI, Oswestry Disability Index (0–50). The clinical success rate represents the proportion of patients with excellent or good outcomes according to the modified Macnab criteria. <i>P</i> < 0.05 was considered statistically significant.			

Figures

Fig. 1

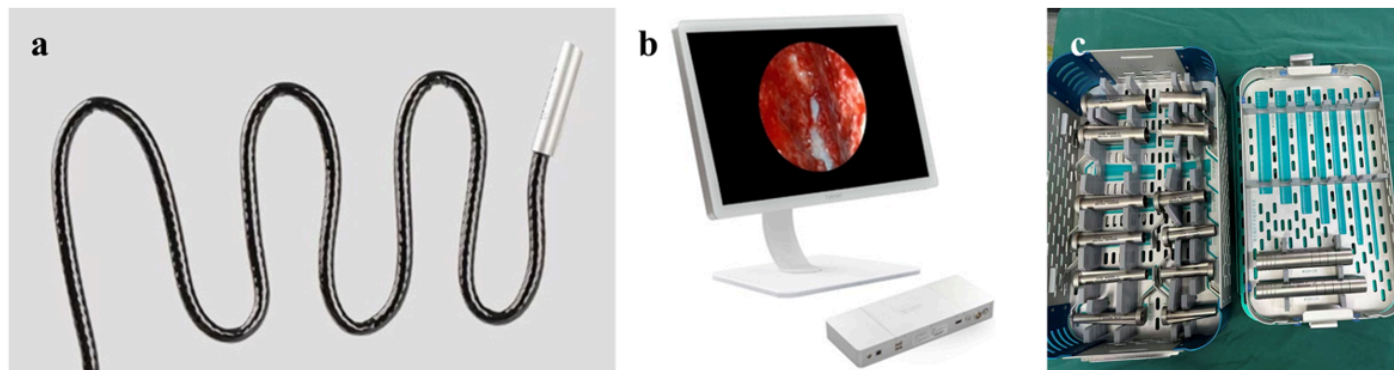


Figure 1

Schematic diagram of the electronic flexible endoscope (a). Display monitor (b). Surgical dilation channels with different diameter gradients and lengths (c).

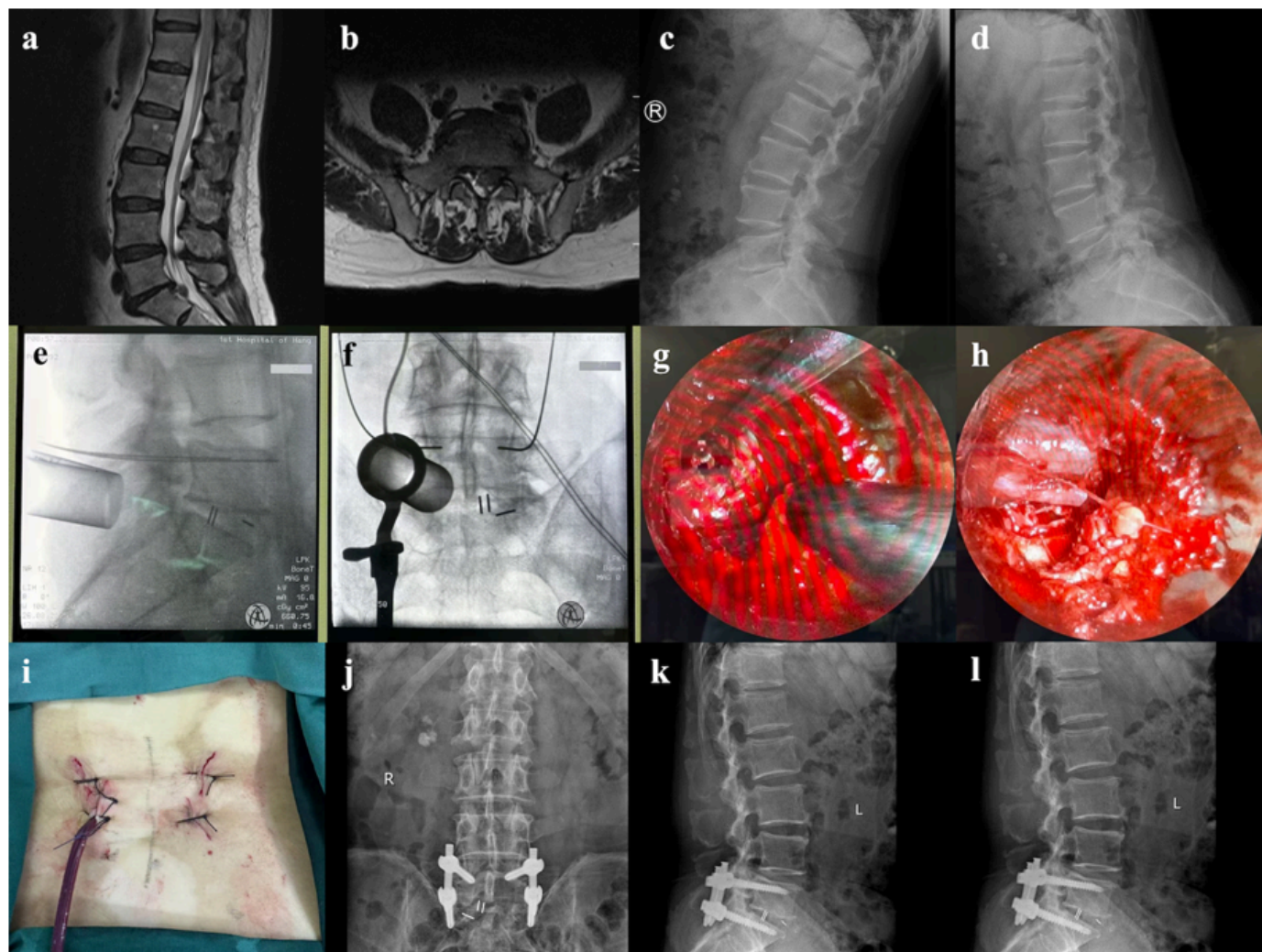


Figure 2

Typical case 1. A 73-year-old man presented with low back pain and left lower limb pain and numbness for 1 year, which had aggravated over the past month. Sagittal MRI (a) and axial MRI (b) demonstrated a massive L5/S1 disc extrusion. Lateral flexion-extension radiographs showed severe disc space narrowing, although the intervertebral segment remained stable (d). Cage implantation under the electronic flexible endoscope and fixed channel. Intraoperative fluoroscopy showed satisfactory cage position with a slight increase in disc space height (e, f). Retraction of the S1 traveling nerve root and cage implantation under the flexible endoscope, with satisfactory decompression of the dural sac and traveling nerve root (g,h). Wound closure (i). Anteroposterior and lateral X-ray one month after surgery (j, k). Lateral X-ray six month after surgery (l).

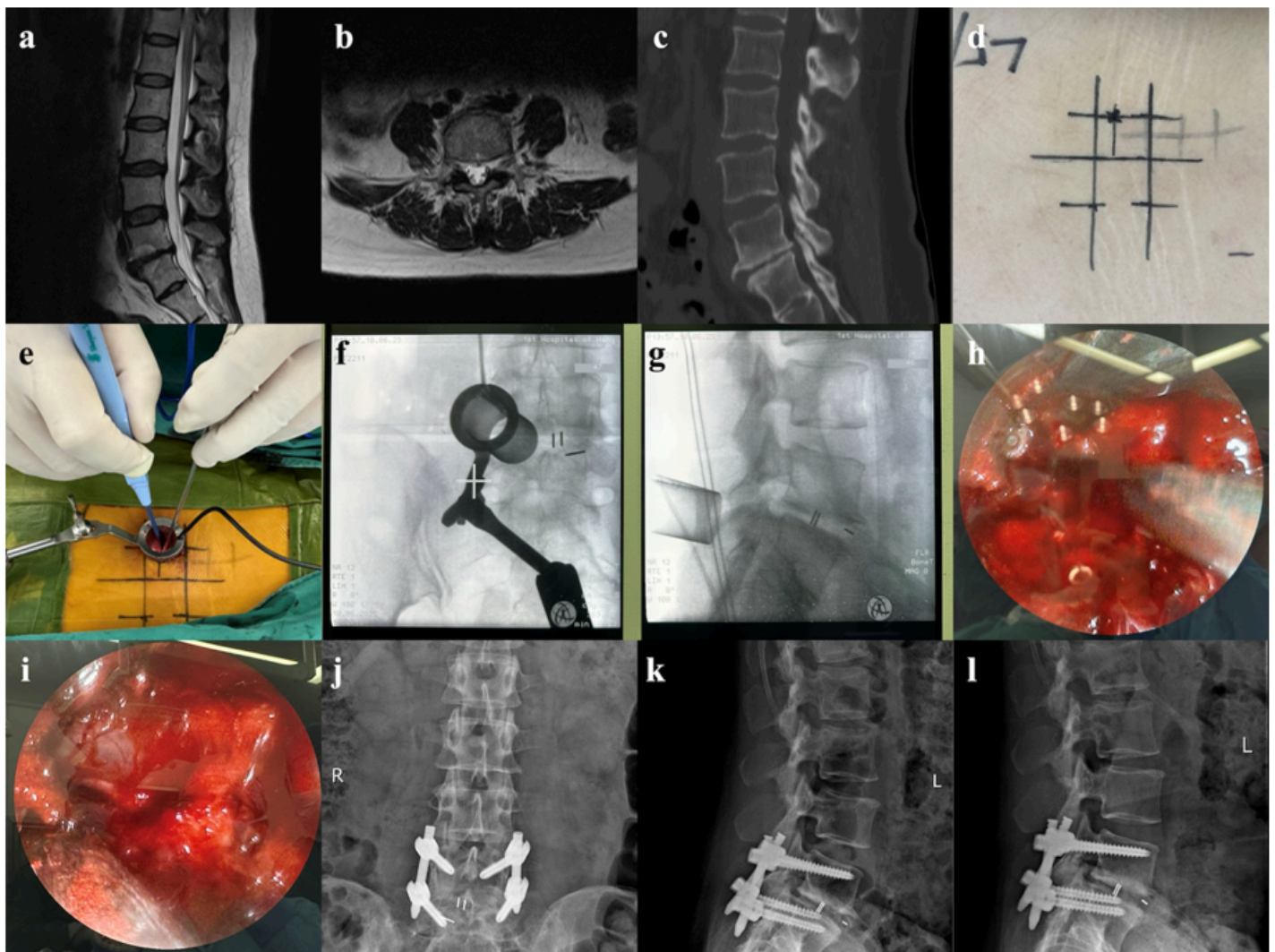


Figure 3

Typical case 2. A 39-year-old woman presented with low back pain and left lower limb pain for over 7 years, which had aggravated over the past 2 months. Sagittal MRI revealed L5/S1 disc herniation with

endplate inflammatory changes (a). Axial MRI revealed L5/S1 disc herniation (b). Sagittal CT revealed severe L5/S1 disc space narrowing with endplate osteochondritis (c). Preoperative incision planning (d). Channel fixation and establishment of the surgical field under the flexible endoscope (e). Cage placement confirmed by intraoperative fluoroscopy (f, g). Under the flexible endoscopic view, the dural sac and traversing nerve root were clearly visualized; small arterial pulsations were visible on the surface of the dural sac, and the cage could be seen after retracting the nerve root. (h, i). Anteroposterior and lateral X-ray one month after surgery (j, k). Lateral X-ray six month after surgery (l).

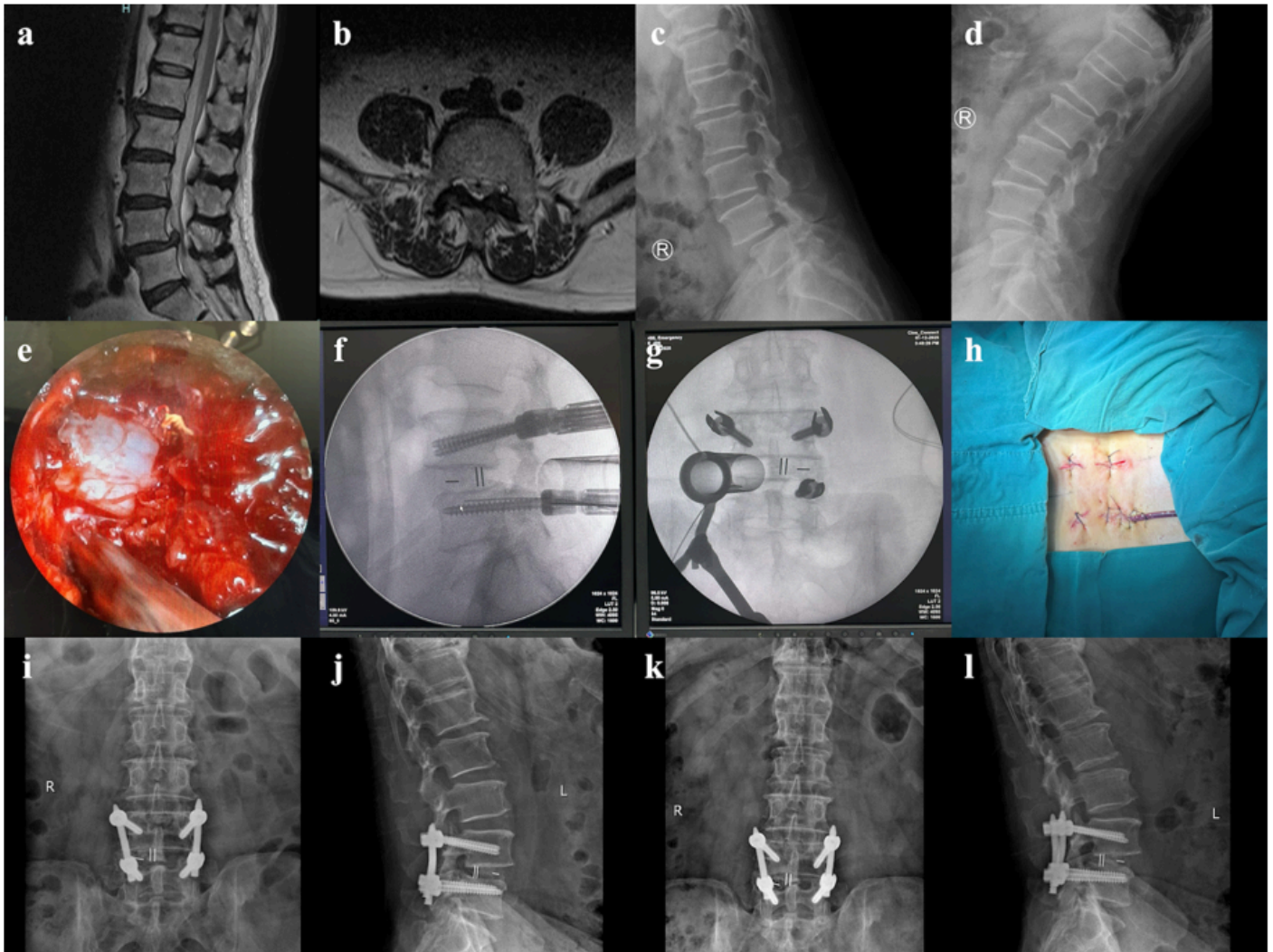


Figure 4

Typical case 3. A 76-year-old man presented with low back pain and left lower limb pain and numbness for 2 years, which had aggravated over the past 1 month. Sagittal MRI revealed L4/L5 disc herniation and spondylolisthesis (a). Axial MRI revealed L4/L5 disc herniation (b). Flexion-extension radiographs revealed L4/L5 segmental instability (c, d). After cage implantation, the dural sac and L5 nerve root were clearly visualized under the flexible endoscope, and the decompression was deemed satisfactory. (e). Intraoperative fluoroscopy confirmed the positions of the cage (f, g). Wound closure (h). Anteroposterior

and lateral X-ray one month after surgery (i, j). Anteroposterior and lateral X-ray six month after surgery (k, l).