



# The evolution of interlaminar endoscopic spine surgery

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**Abstract:** Due to the aging population, patients required spinal surgery for degenerative spondylopathy is increasing. With the advent of surgical instruments and techniques, minimally invasive spine surgery is prevalent worldwide. Besides microscopic techniques, endoscopic spine surgery has gotten attention gradually in this surgical field for the past two decades. There are two essential approaches developed currently, including transforaminal and interlaminar approach. These innovative equipment and skills promote the progression of endoscopic surgery from discectomy to decompression of spinal stenosis. Meanwhile, they also opened up the application of endoscopic surgery in a complicated situation. From the perspective of emerging technologies and techniques, the authors will review the evolution and describe the prospects of the interlaminar endoscopic spine surgery (IESS).

**Keywords:** Endoscopic spine surgery; interlaminar; minimally invasive spine surgery; endoscopic spine decompression

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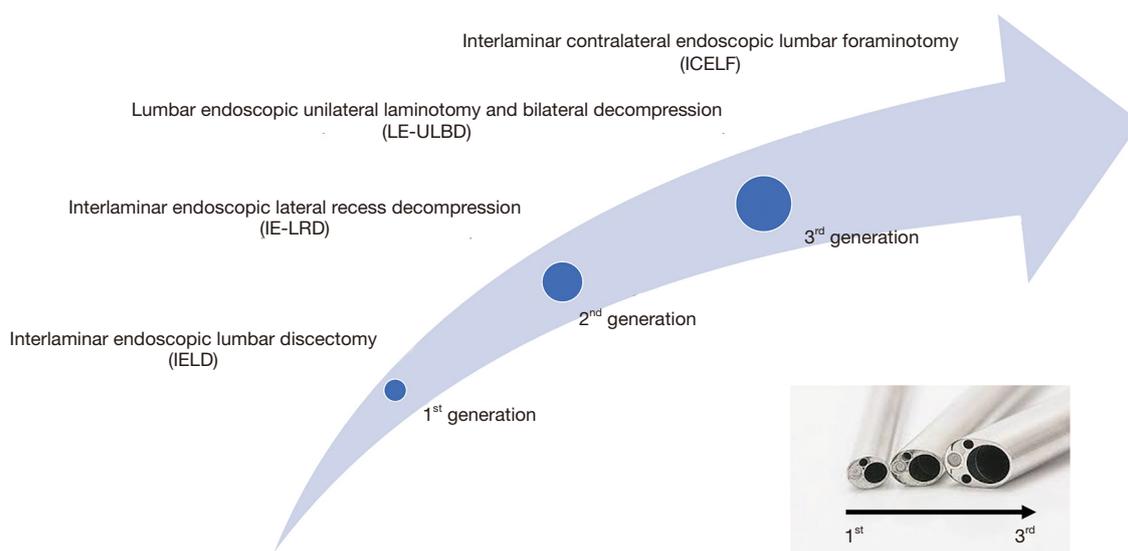
## Introduction

Degenerative lumbar spine disorder is a common and significant cause of disability in the world (1). With the trend of an aging population, degenerative spine disorders lead to an increase of the global burden and a rise of the need for spinal care (2). The concepts of functional preservation and enhancing post-operative recovery have been general consensus in modern spinal care. Therefore, the field of minimally invasive spine surgery has progressed significantly during the past two decades. The advancement of image modalities provides accurate preoperative radiological evaluation and plan. Moreover, with the development of surgical technologies, minimally invasive spine surgery has been prevalent gradually due to minimize damage to non-pathogenic structures, durable effectiveness with less complication rates, and shorter hospital stay (3).

As for minimally invasive spine surgery, full-endoscopic

spine surgery has been a viable option in recent decades. The full-endoscopic surgery is performed with the application of an endoscope that consists of a 20–30-degree rod-lens camera system with a light source, a working channel and an irrigation channel. The design of endoscope provides clear visual control during operation and minimize traumatization to normal soft tissue with uni-portal tract. In comparison to traditional surgery, endoscopic spine surgery provides advantages such as less soft tissue trauma, reduced blood loss, decreased damage to the epidural blood supply and consequent epidural fibrosis, shorter hospital stays, shorter time to return to work (4-8). Through the past decade, the advancement of endoscopic instruments, such as different designs of endoscope and endoscopic burrs or punches, has promoted the technical progress and extensive application of the full-endoscopic spine surgery.

The interlaminar and transforaminal endoscopic spine surgeries have been the representatives for the



**Figure 1** The evolution of the interlaminar endoscopic spine surgeries is based on a progress of the three generations endoscopic system.

endoscopic spine surgery. Each technique has developed many modified skills in treating different pathologies. The interlaminar endoscopic spine surgery (IESS) was proposed after transforaminal technique but it further contributed to expand the indications of endoscopic spine surgery, especially in treating spinal stenosis. In this review, the authors will introduce the evolution of IESS following development of the three generations endoscope system (*Figure 1*) and discuss the application of IESS in the present and future.

### Evolution of IESS

In the early stage, full-endoscopic spine surgery was derived from percutaneous lumbar discectomy. Initially, percutaneous lumbar discectomy was performed under fluoroscopic guidance by posterolateral approach without direct visualization (9,10). In 1991, Kambin developed arthroscopic lumbar discectomy through a “triangular safe zone”, which was recognized as the prototype of modern transforaminal endoscopic lumbar discectomy (TELD) (11). During 1990, most endoscopic operations were performed through transforaminal access with uniportal scope under fluid flow (11-15). The preliminary study of TELD also showed similar efficacy and recurrence rate compared with conventional microdiscectomy in selected patients (5). However, TELD at the L5–S1 level is sometimes technically

challenging due to anatomical limitation of surgical access through posterolateral approach (16). The anatomical studies revealed that the corridor through transforaminal approach to reach L5–S1 foramen may be limited by high iliac crest, smallest intertransverse space, and narrow foramen compared with other levels cranially (17,18). Therefore, interlaminar approach technique was introduced as an alternative solution for full-endoscopic discectomy at L5–S1.

### First generation: interlaminar endoscopic lumbar discectomy (IELD)

In the lumbar spine, the interlaminar window at L5–S1 level was greatest and the width of the interlaminar space was maximum at 31 mm (19). The interlaminar approach for lumbar discectomy has been done with the aid of microscope since 1970s (20-22) and microendoscopic system since late 1990s (23-25). Spine surgeons have been familiar with this corridor by posterior approach to do lumbar spine surgeries. Therefore, IELD was initially considered to be an advanced form of microscopic lumbar discectomy. The IELD represented the discectomy performed with the full-endoscopic system through the interlaminar window. Patients could be in either the prone or the lateral decubitus position. The operation could be performed under conscious sedation, epidural or general anesthesia. The endoscope had an outer diameter of 6mm

and working channel of 2.7 mm (YESS; Richard Wolf, GmbH, Knittlingen, Germany). Usually, the surgeon can insert the endoscope into epidural space for discectomy without doing laminotomy. While reaching epidural space, surgeons could remove herniated disc with aid of forceps or laser through working channel.

In 2006, two pilot studies of IELD for L5–S1 herniated intervertebral disc were reported from Korean and German groups respectively. Choi *et al.* reported 90.8% favorable result among 65 patients with more than 1.5 years follow-up after L5–S1 IELD in Korea (26). Patients were under local anesthesia during surgery and the mean hospital stay was 12 hours. Furthermore, a prospective study reported by Ruetten *et al.* in 2006 also showed a promising outcome in 331 patients who underwent IELD by the same endoscopic equipment and the recurrence rate was 2.4% with 2 years follow-up period (27).

There were two major technical differences between the two groups. First, Choi *et al.* split ligamentum flavum with sequential dilator under fluoroscopic guidance, but Ruetten *et al.* made an incision by 5 mm in the lateral ligamentum flavum under visual control. The ligamentum flavum has an important role in structural integrity and prevention of epidural scarring (28,29). However, the Choi's technique cannot be performed under direct visualization. Thereafter, this ligamental preservation technique was modified by Kim *et al.* with serial dilators under direct visualization of endoscope (30). Second, the Choi's technique included annular modulating procedure with circumferential coagulation of the radiofrequency probe and side firing laser probe. The annular sealing technique can help with the decrease of early recurrence after IELD (31). In a recent report, 96.25% of patients underwent IELD with both these structural preservation techniques could have favorable outcome (32).

In this stage, IELD was effective mainly in treating non-migrated or low-grade migrated soft disc at L5–S1 level. The first-generation endoscopic instruments could only remove soft tissue such as ligament and disc. The osseous diameter of the interlaminar window was the most important factor in assessing the feasibility of IELD. The previous radiological study revealed that the width of interlaminar window in the lower lumbosacral spine L4–5 and L5–S1 usually allows for performing IELD (33). However, lateral drilling is necessary for interlaminar discectomy at upper lumbar levels. Furthermore, there were problems with the small working channel in the endoscope and lack of durable instruments for resection of bone. That is, narrow

interlaminar window results in limited indication for IELD with first generation endoscope system.

### **Second generation: interlaminar endoscopic discectomy with laminotomy**

With the necessity of bony work in endoscopic spine surgery, second generation of endoscope with an outer diameter of 7.9 mm and a 4.2 mm working channel and instruments such as specially designed endoscopic burrs and punches were produced. In 2007, Ruetten *et al.* began to utilize the newly designed optics and instruments to eliminate the bony limitation under full-endoscopic visualization in some cases for removal of migrated disc (34). According to this report in 2007, they had to resect bone segment of the inferior articular process and cranial lamina for discectomy in 14% patients underwent IELD. There was no failure or conversion in the consecutive case series with both interlaminar and transforaminal approach. The large intra-endoscope working channel and tools suitable for laminotomy enabled to enlarge interlaminar window. Subsequent studies also revealed that the treatment of different levels and types of disc herniation was effective with IELD, included level of L4–5 and above.

Moreover, the second-generation endoscope also launched a new era of endoscopic spine surgery. Degenerative lumbar lateral recess stenosis is usually caused by hypertrophic facet joint, herniated disc, and ligamentous structures. Symptoms such as neurogenic claudication with radicular signs can occur in this situation. Microscopic laminectomy has been the main surgical therapy until now. However, with second generation endoscopic system, the technique of interlaminar endoscopic lateral recess decompression (IE-LRD) could also be effective with less tissue damage. In 2009, Ruetten *et al.* firstly reported prospective and randomized controlled study of surgical treatment for lumbar lateral recess stenosis with the full-endoscopic interlaminar approach (7). He applied the second-generation endoscope and 4-mm burr to do lateral recess decompression through ipsilateral interlaminar approach. Decompression was accomplished by cranial and caudal laminotomy, and partial medial facetectomy with endoscopic burr or shaver to unroof unilateral lateral recess. Then, the surgeon could remove the ligamentum flavum with micro-punch and grasping forceps. The ipsilateral traversing root was completely decompressed in the similar fashion of the microsurgical procedure. The clinical outcome of the patients underwent

**Table 1** Comparison of different endoscopic system for spinal stenosis decompression

Variable	RIWO Vertebris stenosis	Joimax iLESSYS Delta	Elliquence	Spinedos LUSTA stenosis	Maxmore S-GUN
Scope profile	OD: 9.3×7.4 mm; WC:5.6 mm; angle: 20°; WL: 117 mm	OD: 10 mm; WC:6.0 mm; angle: 15°; WL: 125 mm	OD: 10 mm; WC:7.1 mm; angle: 15°; WL: 139 mm	OD: 9.3×7.4 mm; WC:7.1 mm; angle: 20°; WL: 117 mm	OD: 9.0 mm; WC:5.5 mm; angle: 11°; WL: 90 mm
Motor system	40,000 rpm	40,000 rpm	50,000 rpm	50,000 rpm	40,000 rpm
Special designed instruments	Articulating bone burr (4.0 mm); oval burr with side guard	Larger diameter endoscopic burr	Bent upwards endoscopic Kerrison	Articulating burr; curved punch; bone biting forceps	Outer tube of endoscopic burr with distal protection
Maximum size of instruments	Kerrison: 5.5 mm; Burr OD: 5.5 mm	Kerrison: 5.5 mm; Burr OD: 5.5 mm	Kerrison: 6.0 mm; Burr OD: 6.0 mm	Kerrison: 6.0 mm; Burr OD: 5 mm	Kerrison: 5.0 mm; Burr OD:4.0 mm

OD, outer diameter; WC, working channel; WL, working length.

endoscopic decompression was the same with the patients with microsurgical decompression. However, the rate of complications and revisions were significantly reduced in the endoscopic group. Patients could have less post-operative pain and rapid recovery to normal life with endoscopic surgery. Therefore, the technique of IE-LRD further expanded the indications of IESS.

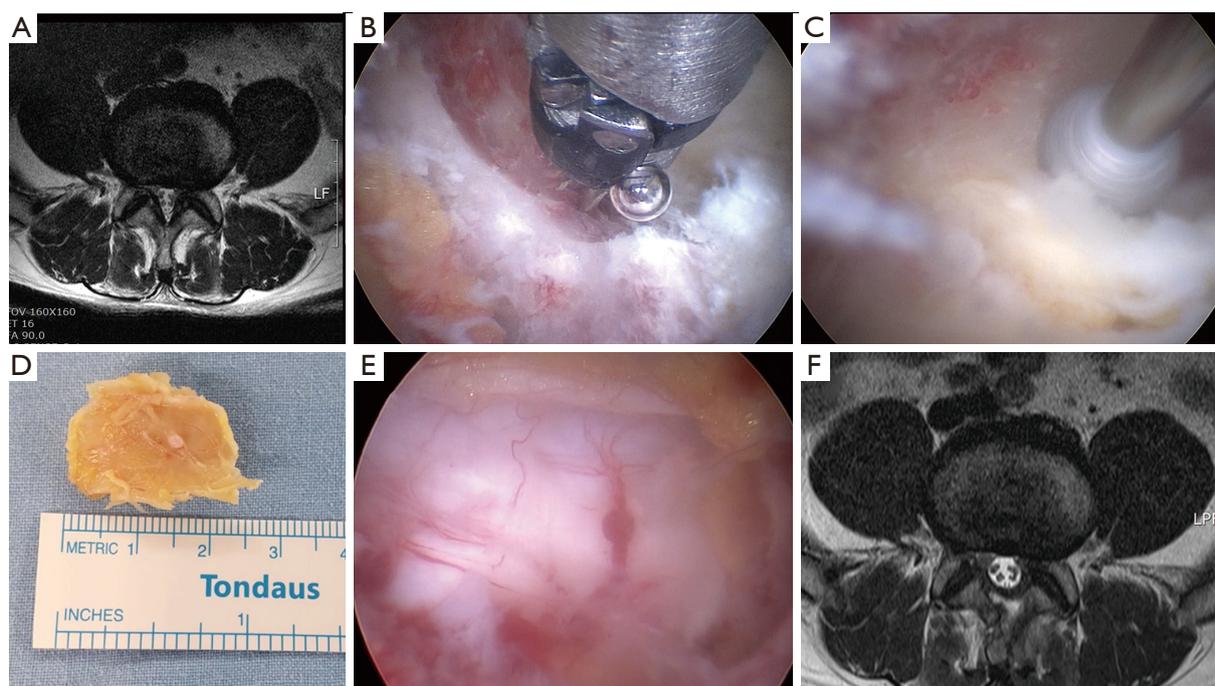
### Third generation: full-endoscopic laminotomy for bilateral decompression

The spinal stenosis in the lumbar spine is the most common degenerative disease that spine surgeons treat (35). It is defined as a reduced cross-sectional area of the vertebral canal. The pathogenesis may arise from serial changes of facet hypertrophy, ligamentous hypertrophy, intervertebral disc bulging, and osteophyte growth. In the perspective of surgical anatomy, there are three stenotic zone included central canal stenosis, lateral recess stenosis, and foraminal stenosis (36). Until now, the most commonly performed surgical treatment for treating lumbar stenosis has been open microscopic laminectomy (37,38). With the advent of endoscopic lumbar discectomy, it became a natural progression to apply the technique to decompress symptomatic spinal stenosis in minimally invasive way.

Although the transforaminal endoscopic decompression is feasible for foraminal or lateral recess decompression, this technique might be impracticable to decompress central canal stenosis (39,40). By contrast, the interlaminar endoscopic decompression is theoretically feasible to

solve central canal stenosis and lateral recess stenosis simultaneously from posterior approach. Khoo *et al.* also reported similar concept of minimally invasive decompressive laminotomy with microendoscopic approach (41). However, it was time-consuming to use small-diameter endoscopic burrs for bilateral laminotomy with second-generation full-endoscopic system. Therefore, the third generation of endoscope with outer diameter of 9.5 mm and working channel diameter of 5.6mm was derived from the demand of the efficient laminotomy (*Table 1*).

Komp *et al.* reported clinical results of 74 patients underwent the interlaminar endoscopic decompression for central spinal canal stenosis in 2011 (42). By using the third-generation endoscope system with burrs up to 5.5 mm in diameter, they developed the technique of lumbar endoscopic unilateral laminotomy and bilateral decompression (LE-ULBD) with removal of ligamentum flavum. First, the ipsilateral decompression was performed by means of cranial and caudal laminotomy, partial facetectomy, and flavum resection. Then, the contralateral decompression was done with over-the-top technique to undercut the contralateral lamina with high-speed burr (*Figure 2*). The mean operating time was 44 minutes (ranged from 35 to 61 minutes) in one segment. The results of LE-ULBD were comparable with conventional surgery but complication rates and revision rates were low. There was also no increased fusion rate in 2 years follow-up after LE-ULBD. Therefore, the LE-ULBD became a standard technique in endoscopic spine surgery for decompression of central canal stenosis.

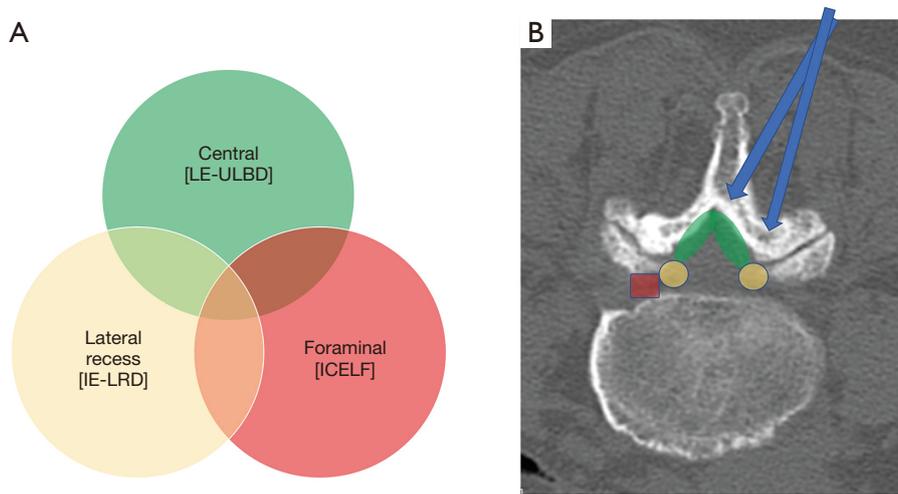


**Figure 2** An illustration of LE-ULBD. (A) The 69 years old male patient had progressive lower legs numbness and neurogenic claudication. MRI at L4-5 level showed central canal stenosis; (B) ipsilateral endoscopic laminotomy; (C) contralateral endoscopic laminotomy with over-the-top technique; (D) en bloc resection of ligamentum flavum; (E) decompression of dural sac and traversing root; (F) post-op MRI showed well decompressed dural sac with preservation of facet joints. LE-ULBD, lumbar endoscopic unilateral laminotomy and bilateral decompression.

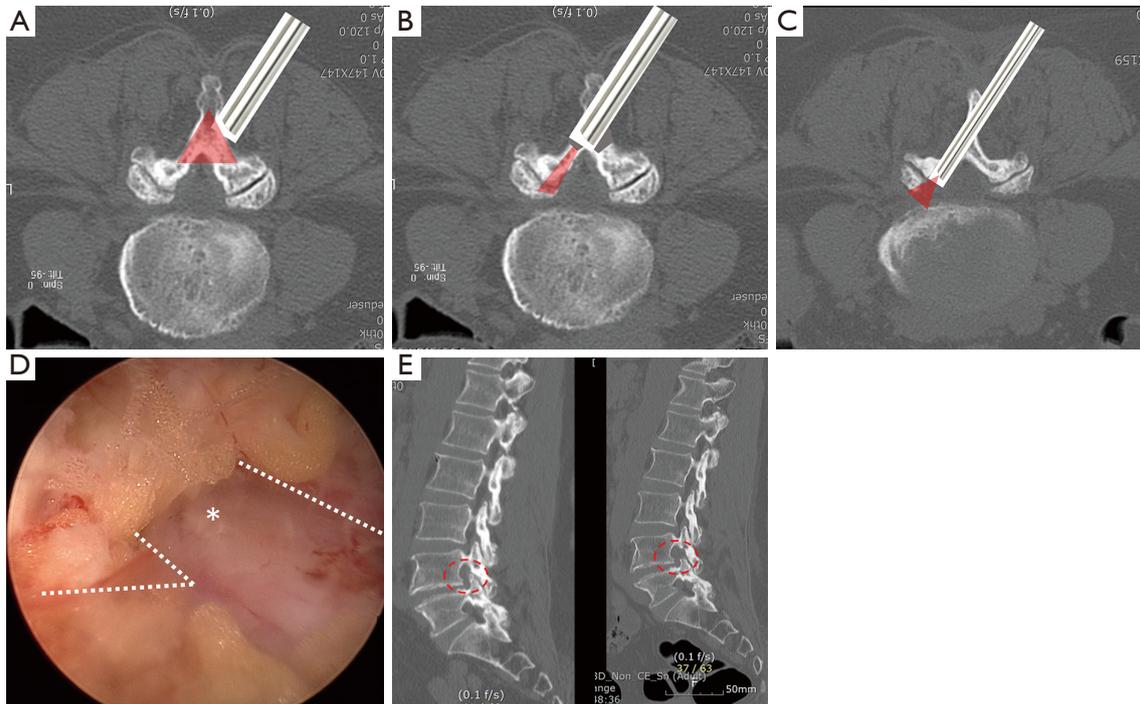
Sometimes, multiple stenotic zones are encountered in lumbar spinal stenosis (*Figure 3*). The common pathologies leading to lateral recess stenosis are hypertrophic facet joint, bulging of the disc annulus or posterior endplate osteophytes (43,44). These degenerative anatomical changes might also result in foraminal stenosis and symptomatic root entrapment at the same time. The intervertebral foramen is usually accessible by transforaminal endoscopic approach. However, the lateral recess decompression is challenging by transforaminal endoscopic route. Besides, the ipsilateral interlaminar endoscopic decompression occasionally requires extensive removal of the medial facet joint on the affected side to unroof the lateral recess and expose the medial pedicle surface, which may result in segmental instability. Therefore, the technique of interlaminar contralateral lumbar endoscopic foraminotomy (ICLEF) was proposed as an alternative to achieve unilateral decompression of the lateral recess and intervertebral foramen (45). By using the burr under direct endoscopic visualization, the base of the spinous process, caudal edge of the upper lamina, and rostral edge of the lower lamina

are partially removed in medial-to-lateral direction from midline to contralateral side. The ventro-medial facetectomy and flavectomy are performed until the traversing and exiting nerve roots were decompressed (*Figure 4*). The clinical results by Hwang *et al.* showed that 14 patients with unilateral radiculopathy had significant improvement of pain and life of quality after contralateral interlaminar endoscopic decompression surgery and there was no dural tear, neurological injury, or revision. In another study by Kim *et al.*, 24 of 26 patients had favorable outcome and only one patient needed revision surgery because of reduced disc height and grade I spondylolisthesis (46).

By using appropriate instruments, the interlaminar endoscopic decompression techniques can provide versatile application in treating all kinds of pathologies safely and effectively (*Table 2*). The third-generation endoscope and newly designed tools improved the efficiency of laminotomy. Through widening interlaminar window, the range of surgical accessibility can improve in transverse plane of the spinal canal. Therefore, surgeons can attain bilateral decompression via unilateral approach to solve central



**Figure 3** (A) The three categories of stenotic pathology and corresponding interlaminar endoscopic surgical solution. (B) To decompress 2 or 3 stenotic pathologies, the surgeons can combine different interlaminar endoscopic techniques. The mobility of interlaminar endoscopic approach in axial sectional plane makes decompression achievable from medial to lateral spinal canal till contralateral foramen. LE-ULBD, lumbar endoscopic unilateral laminotomy and bilateral decompression; IE-LRD, interlaminar endoscopic lateral recess decompression; ICELF, interlaminar contralateral endoscopic lumbar foraminotomy.



**Figure 4** The step-by-step illustration of interlaminar contralateral endoscopic lumbar foraminotomy. (A) Step 1: midline laminotomy. (B) Step 2: drill contralateral lamina and unroof lateral recess of the contralateral side. (C) Step 3: decompress contralateral foramen by undercutting medial facet and removing ligamentum flavum. (D) Endoscopic visualization of decompressed root (\*). (E) The pre-operative (left) and post-operative (right) CT images showed the widened foramen (dotted line circle) after removing the tip of superior articular process.

**Table 2** Comparison of the endoscopic profiles in different generations

Variable	1 <sup>st</sup> generation endoscope	2 <sup>nd</sup> generation endoscope	3 <sup>rd</sup> generation endoscope
Mechanical profile	OD: 6 mm; WC: 2.7 mm; angle: 20°	OD: 6.9 mm; WC: 4.2 mm; angle: 25°	OD: 9–10 mm; WC: 5.5 mm; angle: 12–20°
Essential working instruments	Trephine, grasping forcep, RF bipolar probe	Endoscopic burr 3.0–4.0 mm; Kerrison punch 4.0 mm	Endoscopic burr 4.5–5.5 mm; Kerrison punch 4.5–5.5 mm
Indication	Discectomy; non-migrated or low-grade migrated disc; mainly L5–S1 or some L4–5 disc herniation	Lateral recess decompression; discectomy (all level); interlaminar contralateral foraminotomy	ULBD; lateral recess decompression
Advantage	Less injury to normal structures; directly pass through interlaminar window	Bony resection is feasible; most versatile application	Efficient in bony work; good resolution of visualization
Limitation	Lack of instruments for bony work; only for discectomy at lower lumbar level	Time consuming while conducting wide laminotomy	Limited movement of endoscope in lateral epidural space

**Table 3** Current indication of interlaminar endoscopic spine surgery

Indication and related patho-anatomy
Lumbar disc herniation
Location: paracentral or foraminal
Migration: no limitation
Level: from L2 to S1 level
Lumbar spinal stenosis without significant instability
Central canal stenosis: hypertrophic yellow ligament
Lateral recess stenosis: hypertrophic ligamentum flavum, hypertrophic facet joint, or synovial cyst
Foraminal stenosis: hypertrophic ligamentum flavum or facet joint

canal, lateral recess, and contralateral foraminal stenosis simultaneously. Besides, the endoscopic decompression techniques can minimize injuries to the facet joints and the posterior midline structures, which might have a beneficial effect on preserving spinal stability. Hence, the interlaminar endoscopic surgery has been widely accepted and utilized in the full-endoscopic lumbar spine surgeries.

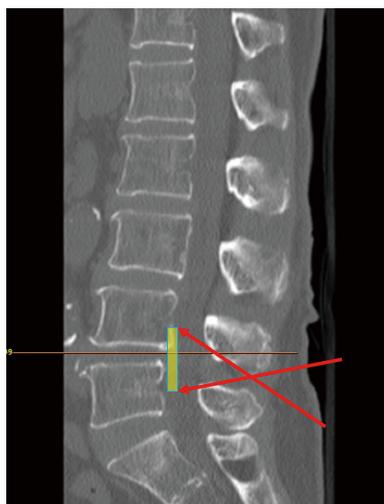
### Present application of interlaminar endoscopic techniques

The mobility of interlaminar endoscopic technique provides broad indication in dealing with all kinds of patho-anatomies (Table 3). For surgical treatment of high-grade migrated disc herniation, patients underwent TELD had

worse clinical and radiological outcomes than those with near-migrated discs and therefore open surgery should be considered (47,48). Although TELD with foraminoplasty by partial removal of ventral facet and/or pedicle could increase the width of the foramen and expose the anterior epidural space, IELD could reach the far-migrated fragment without destruction of facet joint or pedicle, which may cause subsequent instability. Through the interlaminar window, the cranio-caudal trajectory of the endoscope is flexible and can be designed according to migrated fragment evaluated on pre-operative images (Figure 5). For selected patient with high-grade down-migrated L4–5 disc herniation, L5–S1 IELD could also remove sequestered disc through wide interlaminar window without bony destruction (49). In circumstances with overhang lamina, surgeons can utilize tailored laminotomy to widen the interlaminar window and switching different sizes of endoscope to reach far-migrated disc fragment (Figure 6).

### The future of IESS

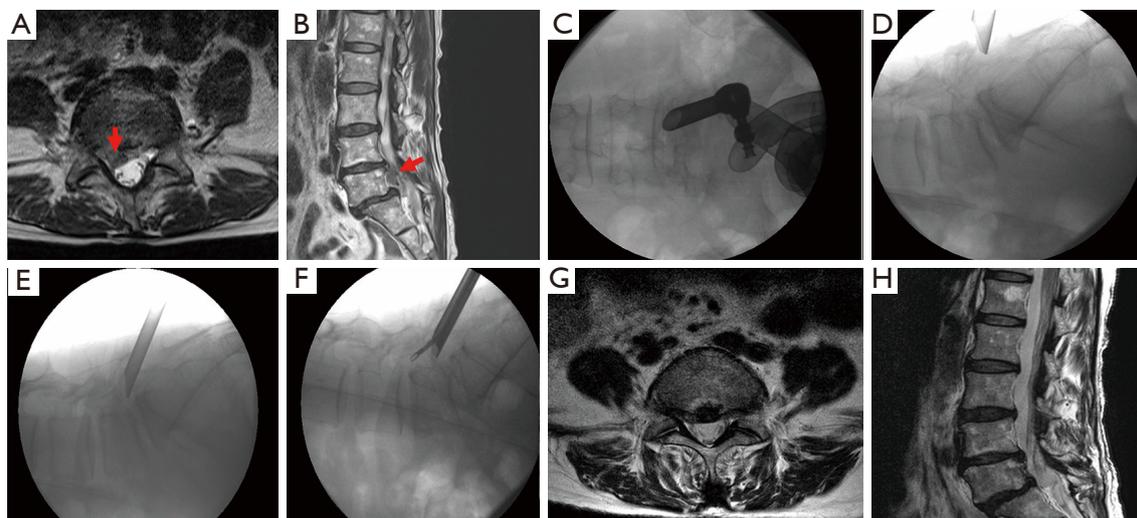
For the past decade, the advancement of IESS has focused on the neural decompression from various pathologies. Clinical evidence has accumulated rapidly and the full-endoscopic surgical techniques have been proven to be effective and safe for treatment of degenerative lumbar spondylopathy. IELD is continuously evolving and standardized. However, steep learning curve remains an obstacle to promote endoscopic spine surgery. Nowadays, the CT-based intraoperative navigation system is available and feasible in minimally invasive spine surgery, especially



**Figure 5** The range of the interlaminar endoscopic approach in sagittal plane (yellow column). By the interlaminar approach, surgical trajectory is flexible and determined according to patho-anatomy on pre-operative images.

spinal instrumentation. The recent report indicated that the navigation improved the learning curve of full-endoscopic lumbar discectomy (50). Moreover, radiation exposure to the surgeon is also an important issue and adequate protection equipment such as lead apron is essential (51). The surgeons are free from radiation exposure and while doing surgeries assisted with navigation system (52). Therefore, navigation guided full-endoscopic spine surgery, such as LE-ULBD or full-endoscopic lumbar foraminotomy, will emerge to improve the learning curve and safety of spine endoscopic surgery.

Recently, some reports about applications of interlaminar endoscopic surgery in spinal stenosis or intervertebral disc herniation of thoracic spine have been reported (53-55). The application of IESS in the cervical spine is also emerging (56,57). With more clinical evidence reported, the indication of IESS may also include the thoracic and cervical spinal surgery in the future.



**Figure 6** A 65-year-old female patient had sudden onset right leg radiating pain during traveling. (A,B) The MRI showed a high-grade downward migration of L4-5 herniated intervertebral disc (red arrow) which resulted in right L5 root compression. (C,D) Interlaminar endoscopic lumbar discectomy was performed from L5-S1 interlaminar window. The right L5 laminotomy was performed with 3rd generation endoscope initially to increase working space to reach herniated fragment. (E) The endoscope was changed with 2nd generation endoscope with smaller diameter after tailored right L5 laminotomy to decrease bony destruction. (F) The endoscopic forceps were inserted to remove far-migrated fragment. (G,H) The post-operative MRI revealed successful fragmentectomy.

## Conclusions

In terms of the IESS, the interlaminar window is like the door to all kinds of pathologies. The endoscopic surgical instruments, such as endoscopic burr, Kerrison, and endoscope with larger diameter, are the keys to open the interlaminar window. The improvement of endoscopic tools drives the evolution of the IESS by widening the interlaminar window. Furthermore, it also broadens the indications of the endoscopic lumbar spine surgery. In the future, comparison studies between different techniques of minimally invasive spine surgery and the application in thoracic and cervical spine surgeries may be the direction of future development.

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