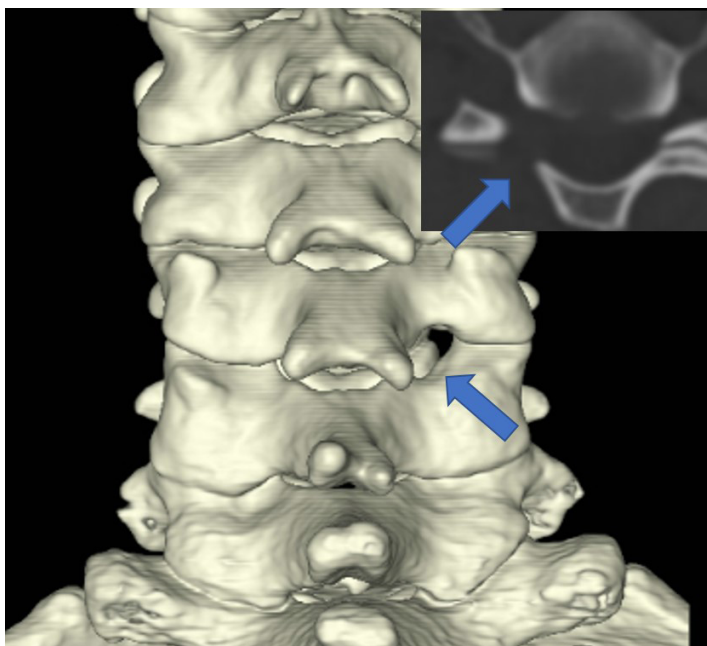


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## Minimally Invasive Approach to the Lumbar Foraminal Pathology



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### Aims and Scope

*Journal of Minimally Invasive Spine Surgery & Technique (JMISST)* is the official journal of the Korean Minimally Invasive Spine Surgery Society (KOMISS), Minimally Invasive Spine Surgeons Association of Bharat (MISSAB), Taiwan Society of Minimally Invasive Spine Surgery (TSMISS), Taiwan Society of Endoscopic Spine Society (TSESS), and Brazilian Minimally Invasive Spine Surgery Society (BRAMISS) for the publication of research results about minimally invasive spinal surgery (MISS). JMISST will consider submissions in areas of endoscopic spinal surgery, minimally invasive procedure for degenerative spine disease, pain intervention, minimally invasive surgery for spinal fusion or spine trauma, neuroscience, neurology, molecular biology and biomechanics etc. JMISST provides spine physicians and researchers with peer-reviewed articles on minimally invasive spine surgery to improve patient treatment, education, clinical or experimental research, and professionalism. In particular, minimally invasive spine surgery, including endoscopic spinal surgery, will be the most important field in the future spinal treatment. JMISST is the only journal in the world that is currently focused on minimally invasive spine surgery. We aim to lead the field of minimally invasive spine surgery to be developed in the future, and will contribute to providing a happy life for humans based on academic development.

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# Lumbar Foraminal Stenosis Is a Combined Pathology With Spinal Canal Stenosis, Leading to the Emergence of New Concepts in Spinal Endoscopic Approaches for Its Treatment

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Endoscopic spine surgery (ESS) has become the new paradigm of minimally invasive surgical techniques, with the advantages of minimized surgical trauma and innovative surgical approaches [1-6]. The surgeon's eye at the tip of the endoscope can observe every corner of the spinal canal, and instruments can access everywhere that can be seen with the endoscopic camera [7,8]. The positioning of the skin entry is flexible because muscle retraction is unnecessary during ESS. These benefits enable the development of creative and groundbreaking surgical techniques.

Lumbar foraminal stenosis is a lumbar degenerative disease caused by facet joint hypertrophy and disc height narrowing. Foraminal stenosis is not a standalone condition but rather a combination of pathologies with lateral recess stenosis. Surgeons tend to choose the surgical approach based on the severity of stenosis and symptoms, whether it's a transforaminal or interlaminar endoscopic approach. Treating both pathologies within and outside the spinal canal is technically demanding without lumbar fusion. Untreated stenotic lesions can lead to persistent pain or early recurrence of symptoms, necessitating additional surgery or procedures to relieve the symptoms.

Therefore, a new concept of an endoscopic surgical approach is necessary to simultaneously treat the combined pathologies of foraminal and lateral recess stenosis. Interlaminar contralateral endoscopic lumbar foraminotomy has proven to be the ideal surgical approach to relieve lateral recess and foraminal-extraforaminal stenosis using a full endoscopic and biportal endoscopic system [9-11]. The endoscopy accesses the lumbar neuroforamen parallel to the exiting nerve root and decompresses the exiting nerve root from the lateral recess to the extraforaminal area. This technique has shown enhanced outcomes even at the L5-S1 level and in patients with lumbar spondylolisthesis.

In this new era of ESS, the *Journal of Minimally Invasive Spine Surgery and Technique* (JMISST) encourages surgeons to present challenging and unique endoscopic techniques, including full and biportal spine surgery [12,13]. Both methods have pros and cons and synergistically contribute to creating new approaches, significantly expanding their applications [14].

JMISST has published advanced endoscopic techniques to address multifocal stenosis problems, including endoscopic lumbar interbody fusion [15,16] and decompression surgery through transforaminal and interlaminar contralateral approaches [17,18]. However, there are still unresolved issues with lumbar foraminal stenosis in various cases. The development of new surgical methods may imply that the treatment for lumbar foraminal stenosis has not yet been established.

JMISST has planned a special issue titled "Minimally Invasive Approach to Lumbar Foraminal Pathology" to provide an in-depth understanding of the complex pathologies of lumbar foraminal stenosis and play a pivotal role in selecting better surgical techniques. This issue discusses the definition of lumbar foraminal stenosis and various surgical approaches encompassing a wide range of combined diseases. By promoting a comprehensive understanding of the complex pathologies of foraminal stenosis and surgical techniques, we hope to provide valuable insights to surgeons and guide them in selecting ideal surgical approaches.

We are deeply grateful to the editorial team who passionately participated in this special issue.

## NOTES

### Conflicts of Interest

Ji Yeon Kim is an editorial member of *Journal of Minimally Invasive Spine Surgery and Technique* but was not involved in the peer reviewer selection, evaluation, or decision process of this article. There are no conflicts of interest to declare.

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# Overview and Prevention of Complications During Fully Endoscopic Lumbar Spine Surgery

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Fully endoscopic lumbar surgery has emerged as an alternative technique to classic open microscopic laminectomy or discectomy. It is gaining popularity due to its advantages in terms of minimal invasiveness, while achieving equivalent clinical outcomes. Remarkable technical developments in surgical techniques and instruments have expanded the indications of this surgical method. However, as the utilization of endoscopic surgery increases, related complications inevitably arise and become major clinical issues. Frequent complications include failure to achieve adequate decompression, early recurrence, and the possibility of wrong-level surgery. Intraoperative and perioperative complications can include postoperative sensory changes related to neural injury, dural tears, hematoma, infection, and rarely, water pressure-related problems. This review article presents an overview of the possible intraoperative and perioperative complications associated with uniportal full-endoscopic surgery. We also discuss the pitfalls that can lead to unexpected devastating results. Additionally, we briefly review potential preventive efforts that can help reduce the risks. The objective of this presentation is to reinforce the basic principles and introduce key technical tips for full-endoscopic spine surgery, ultimately leading to clinical success and the prevention of complications.

**Key Words:** Endoscopic surgery, Spine, Lumbar, Complication

## INTRODUCTION

Spine surgery has experienced significant technological advances in recent decades, one of the most notable being the introduction of endoscopic techniques. Full-endoscopic lumbar spine surgery has demonstrated potential for better clinical outcomes, faster recovery, and less postoperative pain compared to traditional open surgery [1,2]. However, similar to other surgical procedures, it does not come without its complications [3,4].

Endoscopic lumbar spine surgery involves the use of an endoscope to perform surgery on the lumbar region of the spine,

typically to relieve pressure on nerve roots or the spinal cord caused by herniated discs, bone spurs, or spinal stenosis [5]. Due to the minimally invasive nature of the procedure, it is often associated with less blood loss, shorter hospital stays, and reduced soft tissue trauma compared to open surgery. Nevertheless, understanding potential complications and their preventive strategies are crucial for enhancing patient safety and outcomes.

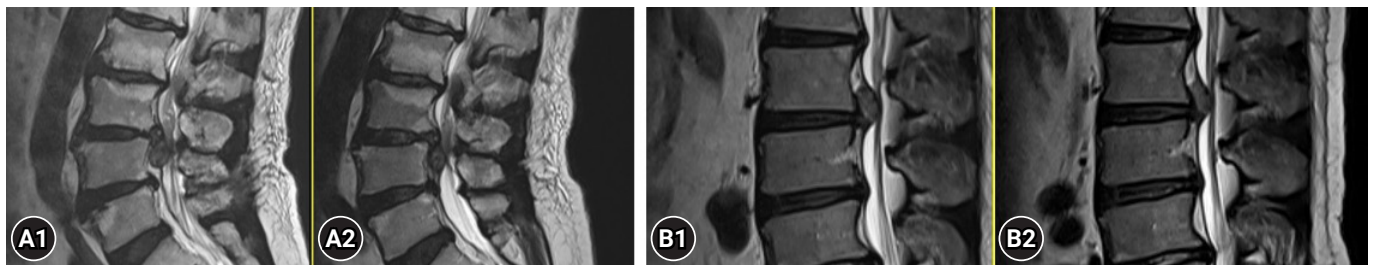
This paper seeks to provide an overview of potential complications associated with full-endoscopic lumbar spine surgery and highlight preventive measures that can be implemented to mitigate them. This knowledge is essential for surgical teams to



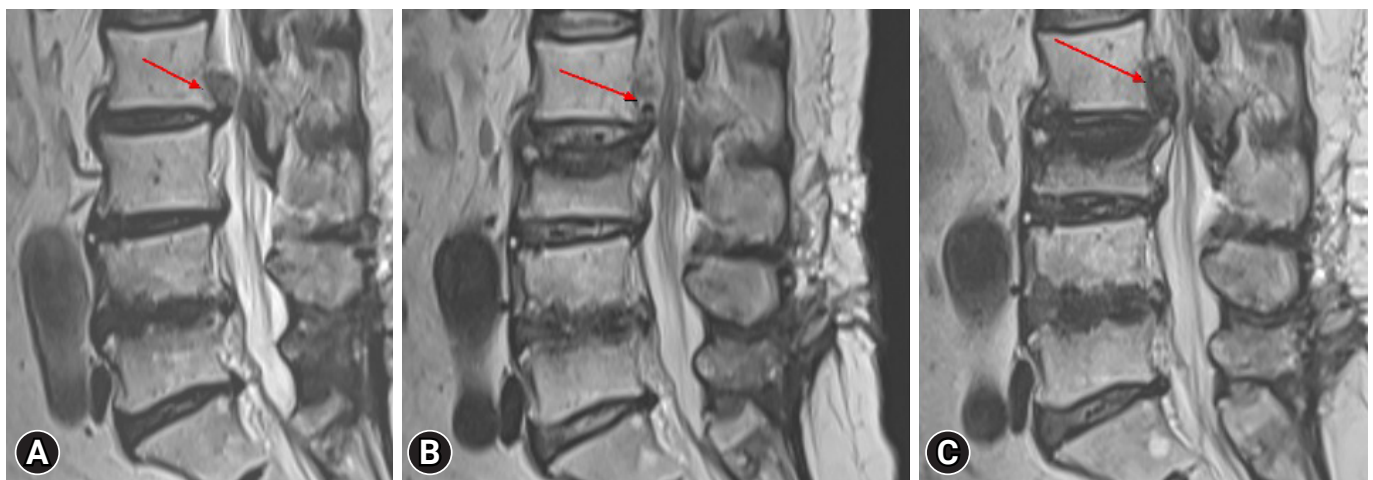
anticipate, recognize, and manage complications should they occur. Through this paper, we aim to contribute to the ongoing dialogue and research surrounding full-endoscopic lumbar spine surgery, with a focus on enhancing the patient-centered care approach and promoting best surgical practices. The narrative review on the complications of endoscopic spine surgery was conducted using a comprehensive methodology to ensure a comprehensive analysis of the available literature. In addition to review of the existing literature, the authors' experiences were added throughout the review, and these findings were synthesized and presented in a narrative format, providing a comprehensive overview of the various complications, their incidence rates, potential risk factors, and strategies for prevention and management. The methodology employed in this narrative review ensured a systematic approach to identify and synthesize the existing evidence on complications associated with endoscopic spine surgery, thereby contributing to a better understanding of this important aspect of the procedure.

## INCOMPLETE SURGERY AND RECURRENCE

Incomplete surgery can be defined as a possible complication that results in remnant spinal pathology related symptoms on the operated side, even after decompression of the spinal neural structures or removal of intervertebral disc materials (Figure 1). The time window defining incomplete surgery differs by each study, however generally incomplete surgery refers to remnant symptoms requiring additional treatment immediately after the surgery, while remote reappearance of symptoms within a certain period usually are categorized as recurrence. Recurrences usually have a transient period of resolution of the preoperative symptoms following a significant reappearance of the similar or sometimes even worse symptoms (Figure 2). Both incomplete surgery and recurrence after an endoscopic spine surgery are relatively common complications. Choi et al. [6] reported that incomplete surgery occurred in 2.8% of their 10,228 endoscopic discectomy cohorts at a single center. Although all



**Figure 1.** (A) Representative preoperative and postoperative magnetic resonance imaging (MRI) of remnant L3/4 down-migrating disc material indicating incomplete surgery. (B) Another representative MRI presenting incomplete removal of up-migrated disc material at the L3/4 level. A1 and B1, preoperative; A2 and B2, postoperative.



**Figure 2.** Representative magnetic resonance images present a recurrent disc rupture after a successful removal of disc materials. Depict the preoperative image (A), immediate postoperative image (B), and final follow-up image (C), respectively. Arrows indicate disc materials.

incomplete surgeries or recurrences do not necessarily lead to reoperations, various studies have reported 2% to 15% rate of reoperations related to incomplete surgery or recurrence [7-9].

Occurrence of incomplete surgeries are usually related to inappropriate or suboptimal surgical approach of the endoscope, misunderstanding of the characteristics of the disc herniation or neural compression and sometime related to challenging cases [6,10,11]. Therefore, thorough preoperative optimization of the best surgical corridor and deep understanding of the individual characteristics of each spinal pathology can lead to lower risk of incomplete surgeries. Another possible preventive measure is utilization of modified techniques of endoscopic surgery. The wide acceptance of endoscopic spine surgery naturally leads to modifications in techniques that optimize procedures for each unique clinical situation, including modifications that offer advantages for lesser risk for incomplete surgeries [12]. There are several additional intraoperative measures that help surgeons determine whether adequate decompression has been achieved or not. Inspect the full free mobilization of the nerve root with careful examination on both the beginning and endpoint of neural structures, repeatedly open and close the water outflow to observe the spontaneous pulsation of the dura which indicates good decompression [13].

Although a widely agreed consensus on the specific time period to define recurrence after endoscopic spine surgery is lacking, it is well-established that the rate of recurrence following an initial procedure is estimated to be approximately 0.5% to 1.5% [6,14,15]. An interesting fact about recurrence after endoscopic spine surgery is that the overall recurrence rate is not that different from conventional microscopic discectomies, however they tend to recur more earlier [15]. Although we have not yet found an ideal solution for decreasing the risk of recurrence, optimized surgical strategies such as determining the appropriate amount of disc removal or performing radiofrequency ablation annuloplasty after removal may provide assistance. Absolutely, considering the natural course of degeneration of the intervertebral disc after an endoscopic surgery is also important when planning any intervention or treatment. The postoperative change of the intervertebral disc is inevitable and can have a significant impact on the clinical outcome and long-term consequences of any intervention [16].

## POSTOPERATIVE HEMATOMAS

Just like any other spinal surgical procedures, unexpected bleeding and resultant hematomas can occur after endoscopic spine surgeries. The majority maybe subclinical, asymptomatic

that they can be even unnoticed, but in rare incidences they result in devastating clinical conditions such as neurologic deterioration. Hematomas can occur both at the epidural space or the retroperitoneal space depending on the surgical approach or detailed surgical procedures [17]. Postoperative epidural hematomas that requires surgical evacuation after an endoscopic surgery is reported to be 0.1% to 1% [18-20]. Most of these uncontrolled clinically significant hematomas are due to unexpected injuries to lumbar radicular arteries of any of its' distal branches [17]. Trying to stay posterior to the posterior vertebral body line helps to avoid intervening with major vascular structures and exercising extra caution during the surgery to prevent injury to vessels, especially in the foraminal area, can help reduce the risk of bleeding.

Fortunately, thanks to the nature of full-endoscopic surgeries, which require minimal or no working space during the procedure, there is limited room for bleeding or hematoma formation. As a result, most hematomas that do occur are subclinical or self-limiting in nature for most cases. Nonetheless, we still need to do maximum effort to reduce the risk of any possible hematomas, epidural or retroperitoneal. Applying modified techniques, such as transsuperior articular process approaches for transforaminal surgeries, can be beneficial. This approach involves landing in an anatomical area that has minimal arterial distal branches, specifically the ventral part of the superior articular process. By using this technique, the risk of encountering arterial bleeding can be further reduced.

Regardless of the endoscopic approach – transforaminal or interlaminar, meticulous hemostasis using various measures including radiofrequency ablation, mixture of epinephrine to the irrigation saline, use of hydrostatic pressure for bleeding control and utilization of various commercialized hemostatic agents can also help reducing the risk of bleeding. Thermal nerve injury caused by radiofrequency is another potential secondary injury that can occur after using it for hemostasis during bleeding control. While radiofrequency is an effective measure for preventing bleeding complications, it can also lead to iatrogenic thermal nerve injury if not used with caution. Therefore, maintaining high vigilance during surgery and exercising careful application of radiofrequency at all times are essential to prevent any potential injuries [21].

## NEURAL INJURIES AND IATROGENIC DUROTOMIES

As the primary objective of most endoscopic surgeries is to decompress the neural elements within the spinal canal, un-

expected neural injuries can occur during the manipulation or decompression of neural structures during surgery, and in many cases, they can happen even unnoticed. Although nerve root injuries are rare for experienced endoscopic spine surgeons, they can occur during the early stages of the learning curve for inexperienced surgeons. The most frequent neural injury during transforaminal endoscopic spine surgeries is the irritation of the exiting nerve root, dorsal root ganglia, or possibly the furcal nerve in the foraminal area and the reported rates are ranging from 0.1% to 4% [22]. While iatrogenic neural injuries are uncommon when there is full visualization during surgery, the majority of exiting nerve injuries are known to be related to the transforaminal surgical approach in most cases [13,23,24]. Although even rarer than exiting root injuries during transforaminal approaches, excessive nerve root retraction during interlaminar surgeries can also result in catastrophic traversing root injuries.

Indeed, careful preoperative planning plays a vital role in minimizing the risk of complications and optimizing surgical outcomes. Thoroughly analyzing the imaging studies, such as magnetic resonance imaging or computed tomography scans, allows surgeons to gain valuable insights into the specific anatomical characteristics of the exiting root in individual cases (Figure 3). The utilization of modified techniques in endoscopic surgery can be a potential preventive measure to reduce the occurrence of exiting root injuries in transforaminal ap-

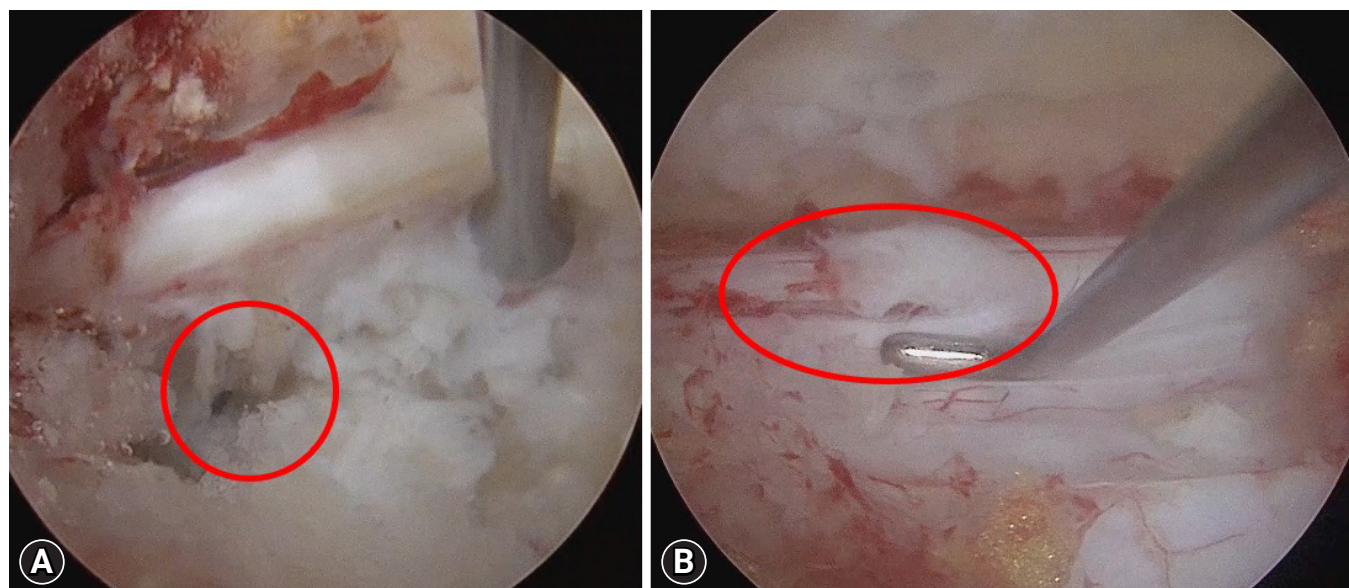
proaches. The transsuperior articular process approach, which focuses on targeting the point farthest from the exiting root within Kambin triangle, can be beneficial in reducing the risk of potential exiting root injuries [25]. This technique aims to minimize the chance of inadvertently damaging the exiting nerve root during endoscopic procedures by precisely navigating and accessing the desired area. By carefully selecting the entry point and trajectory, surgeons can decrease the risk of injury to the exiting root and enhance the safety of the procedure. Unfortunately, there is still no foolproof or perfect way to prevent certain events. In various situations, despite our best efforts, certain injuries may still occur. While we strive to minimize risks and take preventive measures, it is important to acknowledge that we cannot completely eliminate all potential issues or guarantee absolute prevention. Instead, the focus is on implementing best practices, protocols, and guidelines to reduce the likelihood of such events and to manage them effectively when they do occur.

Iatrogenic dural injury is one of a common complication during endoscopic spine surgery procedures (Figure 4). Although it is not frequently seen, if a dural tear does occur, it can lead to cerebrospinal fluid leak leakage, which in turn can cause orthostatic headaches, and in more severe cases, it can result in the formation of pseudomeningoceles that may require additional surgical repairs [26-28]. It inevitably leads to prolonged hospital stay, poor immediate postoperative outcomes and poor patient satisfaction once occurred. While the reported incidence of iatrogenic durotomy during conventional open spinal surgeries varies between studies, ranging from 3.1% to 14% [26-28], there is little reported regarding the rate of durotomy during endoscopic spine surgeries. Although the number of reports on this topic is limited, the currently available evidence suggests that the durotomy rate during endoscopic surgery falls within the range of 0.5% to 7.5% [29-32]. These findings indicate that endoscopic surgery itself does not pose a higher risk for dural injuries compared to open surgery. In fact, the reported rates of durotomy during endoscopic surgery are even lower than those reported for open surgery. Absolutely, despite the lower reported rates of durotomy during endoscopic procedures compared to open surgery, it is crucial to exercise great caution during any endoscopic procedure to avoid injuring the dura. To minimize the risk of dural injury, surgeons performing endoscopic procedures should employ meticulous techniques and adhere to proper surgical principles. Diligent attention and care such as keeping the ligamentum flavum as a dura protector [11], should be taken throughout the procedure to ensure the integrity of the dura is maintained.



**Figure 3.** (A1 and A2) Representative sagittal T2-weighted images demonstrate exiting roots located adjacent to the intervertebral disc (arrow), just ventral to the superior articular process. In such cases, it is crucial to exercise extra caution to prevent any injury to the exiting root. (B) The exiting root is observed to run more cranially to the endoscope landing area in this image, indicating a relatively lower risk of injury.



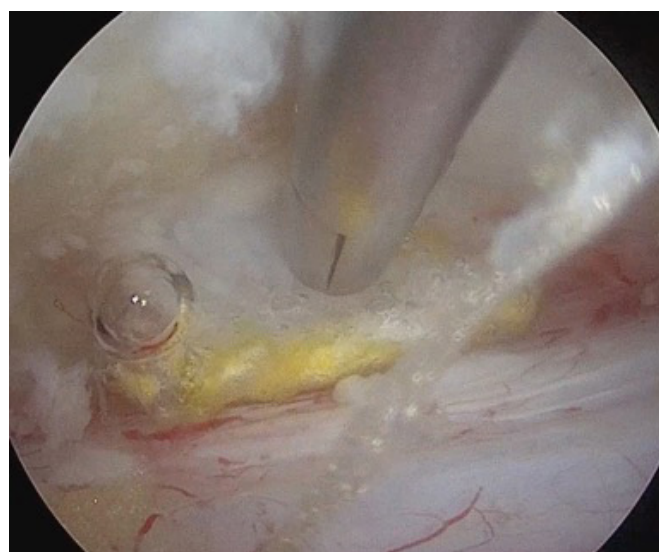


**Figure 4.** (A) Intraoperative view of an unexpected iatrogenic dural puncture (circle) at the ventral side of the traversing root, transforaminal approach. (B) Intraoperative view of an iatrogenic durotomy (circle) at the dorsal aspect of the dura, with an inter-laminar approach.

Due to the limited access and visualization provided by endoscopic procedures, direct repair of a durotomy can be challenging. In such cases, the conversion to an open surgery may be necessary as it provides better exposure and facilitates easier repair of the durotomy. However, it's important to note that this conversion comes at the expense of losing the benefits offered by an endoscopic procedure. Therefore, several full-endoscopic dural repair techniques have been introduced including direct repair of it [33,34], using muscle patches or applying commercially available collagen patches (Figure 5) [31,35]. In most cases durotomies are well managed by these intraoperative endoscopic repairs or sealing techniques without any significant additional complications, with no worsened clinical outcomes. However, in cases where unrepairable and clinically significant injuries are identified, it is important not to hesitate in converting to open surgery to address and repair them. The priority should be the proper management of the injury, even if it means transitioning from the initial endoscopic approach to an open surgical procedure.

## MISCELLANEOUS AND OTHER COMPLICATIONS

Surgical site infection after a spinal surgery is a common complication that occurs in 0.7% to 10% of open surgical cases which is directly linked to surgery related outcome and quality



**Figure 5.** Sealing the durotomy site with commercially available sealants.

of life [36,37]. It is a great socioeconomic burden at the same time. Thanks to the nature of this specific technique that does the entire procedure with continuous aseptic saline irrigation, the reported post operative infection rate is extremely low [6,38]. However, when the cylindrical structure of the endoscope channels is not adequately cleaned and sterilized, there is a risk of unexpected infections occurring at any time. There-

fore, it is crucial to exercise caution and ensure proper cleaning and sterilization procedures are followed.

Water pressure-related complications are additional unique problems that should be taken into consideration. During full-endoscopic procedures, there is continuous infusion and irrigation of saline over the epidural space throughout the surgery. This can be a point of concern as it has the potential to increase epidural pressure at any given time, and in rare cases they can lead to increased intracranial pressure [39]. Although the reported incidence of problems related to increased intracranial pressure is less than 0.1% [6,39], it can occur due to negligence or carelessness in managing the dynamics of saline irrigation. Therefore, it is crucial for endoscopic spine surgeons to ensure proper regulation of infusion using pump irrigation systems or natural drain systems to mitigate the risk.

## DISCUSSION

Full-endoscopic lumbar spine surgery, emerging as a significant milestone in the realm of spinal surgical practice, has been rapidly garnering attention and recognition due to its minimally invasive nature. A paradigm shift from traditional open surgery, this novel approach is underpinned by the core principles of minimally invasive surgery, aiming to achieve the same or better surgical outcomes while causing the least possible disruption to the patient's body. The operational benefits offered by this technique are vast and multifold, ranging from decreased operative trauma to reduced recovery times, and improved patient comfort [2,5,23]. Firstly, the minimally invasive characteristic of this procedure results in reduced tissue injury, lessening surgical trauma. By preserving the integrity of surrounding tissues, full-endoscopic lumbar spine surgery decreases postoperative inflammation and pain, facilitating a faster recovery process for patients. This is a crucial advantage over traditional open surgeries, which typically involve more extensive tissue damage and consequently, longer recuperation periods [40]. Additionally, this method also promises reduced recovery times, enhancing the overall patient experience. Faster postoperative recovery translates into shorter hospital stays, prompt return to daily activities, and reduced healthcare costs—a significant improvement not only in the quality of life for patients but also in terms of broader healthcare economics [2,41]. Enhanced patient comfort is another compelling advantage of this technique. The reduced trauma, faster recovery, and minimal scarring associated with this procedure collectively contribute to an improved patient experience, and higher satisfaction rates [2].

However, while this technique is revolutionizing the field of spine surgery with its impressive advantages, it is important to acknowledge that it is not devoid of potential complications. Just like any other surgical procedure, full-endoscopic lumbar spine surgery carries certain inherent risks and complications. From potential nerve injuries to the risk of disc herniation recurrence, these complications can have significant implications for patient outcomes [1,42]. Therefore, a comprehensive understanding of these potential complications, along with the development and application of strategic preventative approaches, is absolutely crucial in order to ensure optimal patient outcomes and fully realize the transformative potential of full-endoscopic lumbar spine surgery.

One of the potential complications associated with the transforaminal approach is the exiting nerve root injury. Key prevention strategies lie in the accurate assessment of the surgical approach and the precise docking. Safe docking can significantly minimize the risk of nerve root injury [40]. Patients with a narrow foramen present an additional challenge. Such situations may necessitate a foraminoplasty to widen the foramen, using tools like a reamer or drill [43]. Furthermore, it is of paramount importance to prevent the endoscope from exerting pressure on the exiting root by ensuring a proper endoscope trajectory during the surgery.

Durotomy, another frequently encountered intraoperative complication, often necessitates immediate recognition and prompt management to prevent adverse consequences. Preventive measures such as adopting meticulous surgical techniques and fostering enhanced knowledge of the local anatomy can be particularly beneficial [31].

Thermal nerve injury due to radiofrequency is a significant concern that requires attention. This calls for diligent operative techniques, especially when using heat-generating instruments. High vigilance during surgery and careful application of radiofrequency can potentially mitigate such injuries [21]. It is crucial to highlight that safety during endoscopic spine surgery is not solely determined by the intensity of radiofrequency power used but also by the duration of its application. While the intensity of radiofrequency power plays a significant role in achieving efficient tissue ablation and coagulation, the duration of its use must be carefully considered to prevent potential complications. Prolonged exposure to radiofrequency energy can lead to excessive tissue heating and thermal damage, which may result in adverse effects on surrounding structures and tissues. Therefore, surgeons must exercise caution and adhere to established guidelines regarding the appropriate duration of radiofrequency power application during endoscopic spine

surgery. This balanced approach, considering both power intensity and time duration, is essential to ensure patient safety and optimize surgical outcomes in the context of endoscopic spine procedures [21].

Dealing with more rare but highly impactful complications, such as massive or remote epidural/subdural hematoma due to hydrostatic pressure, warrants cautious and controlled use of irrigation during surgery, as well as attentive postoperative monitoring [29,44-46]. This further accentuates the critical role of comprehensive postoperative care.

The risk of disc herniation recurrence represents a significant concern following full-endoscopic lumbar spine surgery. The implications of recurrence can range from prolonged recovery times to the requirement of additional surgical interventions, significantly affecting the quality of life and satisfaction in patients. Certain risk factors have been identified that may increase the likelihood of disc herniation recurrence, including younger age, greater disc height, and advanced stages of disc degeneration. In order to mitigate this risk, a precise surgical technique is critical. The goal should be to achieve an optimal balance during discectomy—enough disc material needs to be removed to alleviate symptoms and avoid immediate postoperative reherniation, but overzealous removal can compromise the structural integrity of the disc and potentially lead to further issues, including recurrence [42]. Moreover, the use of predictive scoring systems as part of preoperative evaluation and patient consultation can further assist in minimizing recurrence risks. Such an approach enables surgeons to better anticipate potential challenges and tailor surgical strategies accordingly, thereby enhancing overall patient outcomes following full-endoscopic lumbar spine surgery.

Moving forward, we need to recognize that the landscape of endoscopic spine surgery is continuously evolving. New technological innovations, surgical techniques, and advancements in our understanding of spinal pathology are likely to introduce new challenges and complications. Hence, commitment to ongoing research, surgical training, and collaboration among the surgical community is essential to continually improve outcomes in endoscopic lumbar spine surgery.

In conclusion, while full-endoscopic lumbar spine surgery provides significant benefits to patients, potential complications need careful attention. Through strategic preoperative planning, meticulous operative technique, and vigilant postoperative care, we can minimize the incidence and impact of these complications and realize the full potential of this transformative technique.

## NOTES

### Conflicts of Interest

JWH, a member of the Editorial Board of *Journal of Minimally Invasive Spine Surgery & Technique*, is the corresponding author of this article. However, he played no role whatsoever in the editorial evaluation of this article or the decision to publish it. Authors have no conflict of interest to declare.

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# Overview and Prevention of Complications During Biportal Endoscopic Lumbar Spine Surgery

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Unilateral biportal endoscopic spine surgery (UBESS) is a minimally invasive surgical technique that has gained popularity for its potential benefits in various spinal lesions. It involves 2 small incisions, providing wide and clear endoscopic visualization, and causes less soft tissue damage than open surgery. UBESS offers flexibility and versatility in approaching different spinal disorders, including decompression of the spinal cord and root in the cervical or thoracic spine, as well as lumbar discectomy and spinal stenosis. One of the strengths of UBESS is its similarity to microscopic techniques, allowing for 2-handed endoscopic surgery. This familiarity makes it easier for surgeons to adopt endoscopic techniques and overcome the learning curve associated with spine endoscopy. However, some potential complications are associated with biportal endoscopic spine surgery, including dural tear, epidural hematoma, infection, incomplete surgery, and neural injury. Although the overall incidence of these complications is relatively low, it is important for clinicians to be aware of them and understand preventive methods.

**Key Words:** Unilateral biportal endoscopic lumbar spine surgery, Complication, Prevention

## INTRODUCTION

Minimally invasive treatments in spine surgery have significantly advanced in recent years. These procedures aim to reduce iatrogenic complications, postoperative discomfort, infection rates, and intraoperative blood loss. By preserving the posterior motion segments and paraspinal muscles, they minimize hospital stays, promote faster healing, and enable quicker return to normal daily activities. Unilateral biportal endoscopic spine surgery (UBESS) has emerged as a minimally invasive technique that has shown clinical effectiveness and safety. It has gained popularity for its potential benefits in various spinal lesions. UBESS involves 2 small incisions, providing wide and clear endoscopic visualization and causing less soft tissue damage. As an emerging endoscopic technique, UBESS offers

flexibility and versatility in approaching many spinal disorders, including decompression of the spinal cord and root in the cervical or thoracic spine, as well as lumbar discectomy and spinal stenosis. Another advantage of UBESS is the ability to perform 2-handed endoscopic surgery, similar to microscopic techniques. This familiarity facilitates the adoption of endoscopic techniques and helps surgeons overcome the learning curve associated with spine endoscopy. However, there are potential complications associated with biportal endoscopic spine surgery (Table 1). A meta-analysis by Liang et al. [1] reported an overall complication rate of 5%, with dural tear being the most common complication at 2%, followed by epidural hematoma with an incidence of 1%. While the overall incidence of these complications is relatively low, it is important for clinicians to be aware of them and understand preventive methods.

## COMPLICATIONS OF UBESS AND THEIR PREVENTION

### 1. Dura Tear

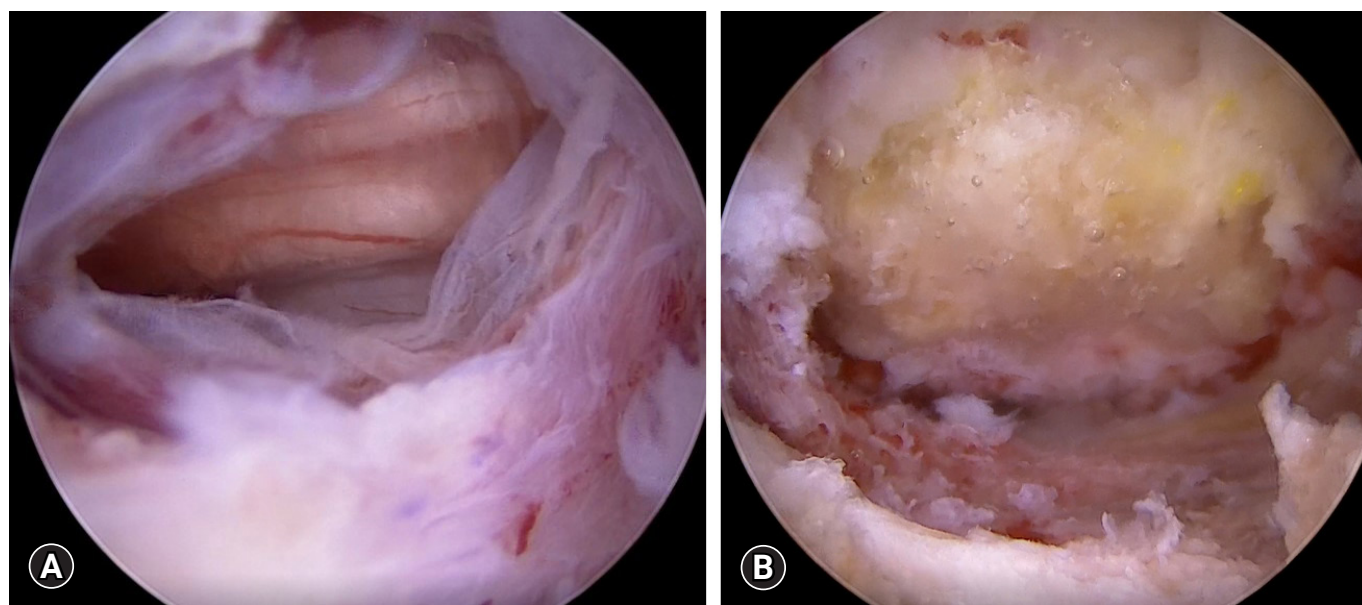
Dural tears are the most common complication in UBESS and have an incidence rate of 1.6%–14%. According to Liang et al. [1], dural injury was reported as the most common complication of UBESS for spinal stenosis, with a prevalence of 2%. During the unilateral laminotomy bilateral decompression procedure, the most common site of dural tear is the dorsal aspect of the dural sac, occurring during the removal of the ligamentum flavum [2,3]. The meningovertebral ligament, a web-like anatomical structure connecting the dura to the lamina and ligamentum flavum on the dorsal side, plays a significant role in these tears [4,5]. This ligament is predominantly located in the midline and can take the form of thin strips or thick sheets [5]. Insufficient dissection of this ligament from the dura can lead to dural tears. In UBESS, while hydrostatic pressure can help separate the dural sac from the ligamentum flavum, folding can occur at the midline due to the presence of the meningovertebral ligament, potentially damaging the dural sac [1]. Lee et al. [2] suggested the use of angled curettes to remove small strips between the ligamentum flavum and dura (Figures 1, 2)

Dural tears may be associated with pseudomeningocele due to cerebrospinal fluid (CSF) leakage, surgical site infection,

or rarely, meningitis. If dural repair is unsuccessful or not adequately treated, these complications can develop [6]. While open surgery typically involves primary repair as the standard treatment for dural tears, endoscopic spine surgery like UBESS does not have a standardized approach for dural tears. Kim et al. [7] proposed that small tears (<1 cm) can be effectively treated with the patch compression method, while large defects ( $\geq 1$  cm) should be repaired using the dura clipping method. Choi et al. [8] suggested that minor tears (<4 mm) could be managed with bed rest alone, whereas larger tears (>12 mm) may require primary repair using a microscope (Figure 3).

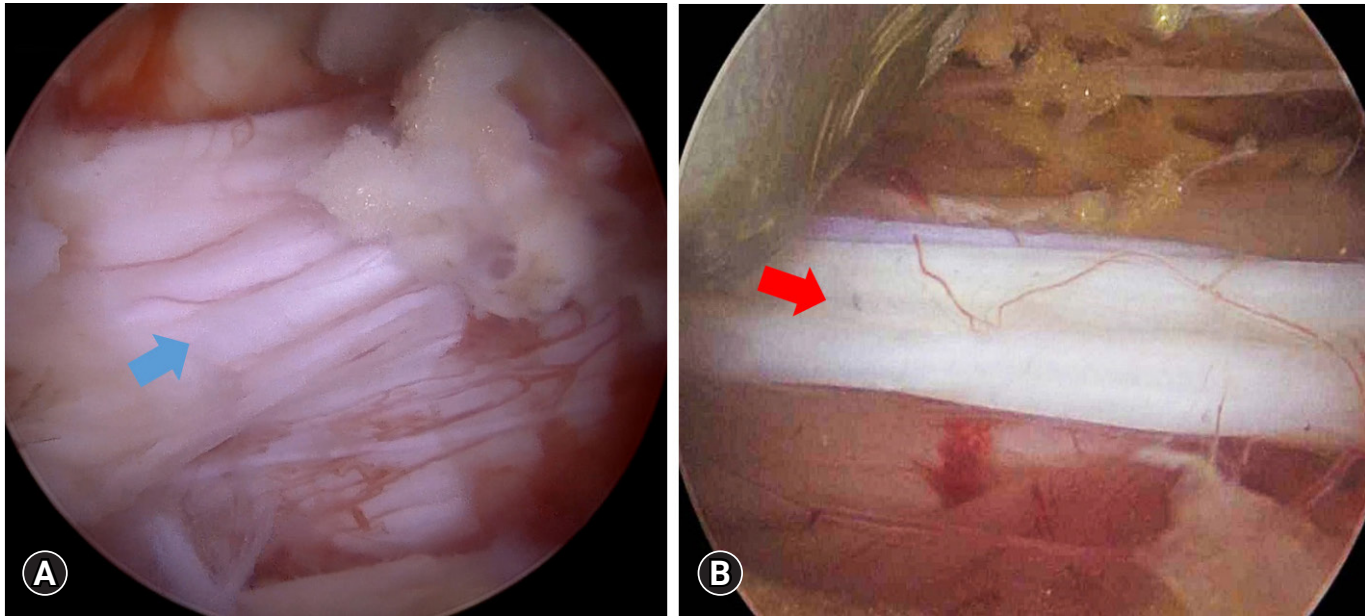
### 2. Epidural Hematoma

Postoperative epidural hematoma is a significant complication of UBESS as it is associated with postoperative infection, epidural fibrosis, or neurological compression [9,10]. In some cases, epidural hematoma can cause problematic compression of the spinal cord or cauda equina, resulting in a significant decline in patients' quality of life. Early recognition of symptoms is crucial for determining whether further evaluation and management are necessary. Symptoms of epidural hematoma include paralysis or bladder dysfunction at the spinal cord level, as well as intractable back pain or radicular pain at the lumbar level, usually occurring within 24 hours after surgery [11]. Mild postoperative hematoma symptoms without neu-

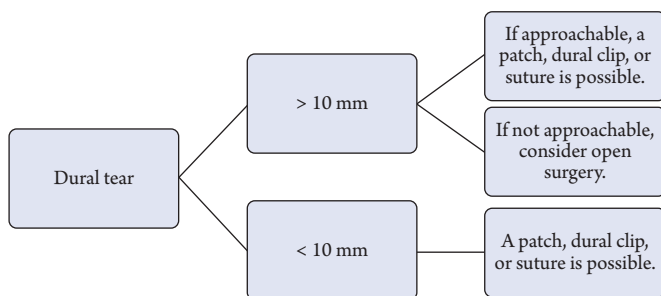


**Figure 1.** Dural tear. (A) Endoscopic view of dural tear (about 10 mm on the dorsal side). (B) Endoscopic view of dural repair with a fibrin collagen patch.





**Figure 2.** Dural fold and posterior epidural ligament. (A) Dural folding due to hydrostatic pressure (blue arrow). (B) Posterior epidural ligament or meningovertebral ligament (red arrow).



**Figure 3.** Treatment algorithm of dural tears.

rological deterioration typically resolve within 3 weeks after surgery, and radiologic regression occurs spontaneously within 3 months after surgery [12]. Several factors contribute to the development of epidural hematoma, including blood pressure control, postoperative drainage, preoperative anticoagulant or antiplatelet medication, and the use of intraoperative saline infusion pumps [13]. Fujiwara et al. [14] reported that patients with hypertension and poor blood pressure control experienced a more pronounced increase in blood pressure during extubation, which could lead to bleeding. Kim et al. [15] found that high water pressure ensures clear endoscopic visualization but may conceal bleeding from epidural vessels or bone.

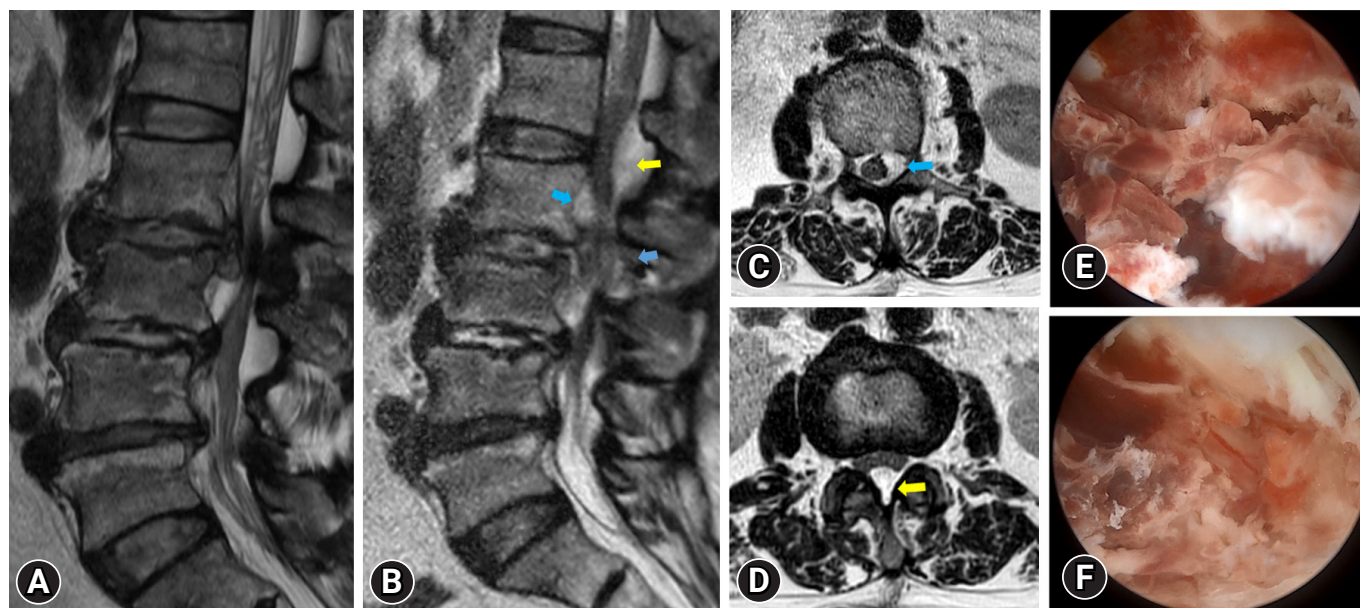
Electrocoagulation is a common method used to control intraoperative bleeding. However, in cases where bleeding control is unsatisfactory, hemostatic materials such as microfibril-

lar collagen, thrombin gelatin, and gelatin-thrombin matrix sealant can be employed. Moreover, the use of bone wax for exposed cancellous bone or the insertion of a hemovac is a useful surgical tip to prevent epidural hematoma (Figure 4).

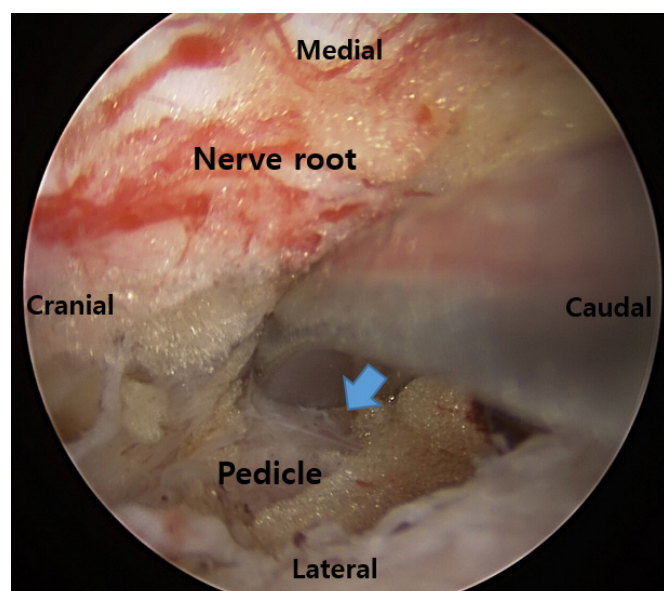
### 3. Incomplete Decompression

While decompression surgery with UBESS for spinal stenosis is usually excellent, in the case of severe lumbar spinal stenosis, decompression could be incomplete. Choi et al. [16] reported that inadequate resection of ligamentum flavum at the crainal and contralateral sides was related to patients experiencing radicular symptoms in their early cases. Choi et al. [16] suggested that angled curettes were more useful than Kerrison punches for performing a proper flavectomy. Angled curettes can scrape the ligamentum flavum under the lamina without requiring extensive laminectomy. To decompress the contralateral side, they recommended partial resection of the upper and lower ends of the spinous processes to create enough space for the insertion of the endoscope and instruments [16]. Moreover, the medial margin of the lower pedicle must be identified for ideal decompression of both nerve roots (Figure 5).

Blurred vision due to intraoperative bleeding can also contribute to incomplete decompression. Meticulous control of systolic blood pressure (below 100 mmHg) and the intermittent use of bone wax and gelfoam can help prevent this complication.



**Figure 4.** A 65-year-old female patient with left leg pain and left leg weakness (G4-). After undergoing discectomy, her radicular pain disappeared and the leg weakness improved. However, 3 days after surgery, she experienced severe left leg pain and developed progressive leg weakness (G2). Magnetic resonance (MR) imaging revealed a postoperative hematoma at surgical site (L2/3), which extended to an upper level (L1/2). Following revision surgery, her radicular pain subsided and her leg weakness improved, but persisted. (A) Preoperative MR image shows herniated lumbar disc L2/3 left with spinal stenosis. (B) Postoperative MR sagittal image shows epidural hematoma (yellow and blue arrows). (C) Postoperative MR axial image shows epidural hematoma at L2 level (blue arrow). (D) Postoperative MR axial image shows epidural hematoma at L1/2 level (yellow arrow). (E, F) endoscopic view of epidural hematoma.



**Figure 5.** End point of lumbar foraminal decompression. The medial wall of the pedicle of the lower vertebrae is touched with a double ended dissector (blue arrow).

#### 4. Recurrence

Recurrence after full endoscopic lumbar discectomy is associated with older age (over 50 years), obesity (body mass index  $> 25 \text{ kg/m}^2$ ), higher lumbar disc herniation, and central disc herniation. Within 6 months, the disease history, Pfirrmann grade, Modic alterations, and migration grade can predict the total recurrence rate following endoscopic lumbar discectomy [17]. The aforementioned risk factors appear to be linked to recurrence of disc herniation. Soliman [18] described a case of recurrent disc herniation in a patient who had undergone UBESS.

#### 5. Instability

Previous biomechanical investigations have found that laminectomies involving the excision of more than 50% of the pars interarticularis increase the likelihood of iatrogenic instability. Iatrogenic instability associated with UBESS could be linked to prolonged drilling of the facet joint, and excessive laminectomies are risk factors for this disorder. In a study by Kim et al. [15], the risk of iatrogenic instability was reported to be 0.6% because



**Table 1.** Overview of complications of unilateral biportal endoscopic spine surgery in the reviewed study

Study	Year	Design	Country	Complications (case number)
Park et al. [3]	2020	RCT	Korea	Dural tear (2), hematoma (1)
Kim et al. [7]	2020	Retrospective	Korea	Hematoma (5), recurrence (16), dural tear (3)
Choi et al. [16]	2016	Retrospective	Korea	Dural tear (2), nerve root injury (1), incomplete decompression (1)
Eum et al. [25]	2016	Retrospective	Korea	Postoperative headache (3), dural tear (2), transient leg numbness (2), hematoma(1)
Czigléczi et al. [29]	2020	Retrospective	Hungary	Postoperative headache (3), dural tear (2), incomplete decompression (1)
Li et al. [31]	2022	Retrospective	China	Dural tear (1), transient paresthesia (1)
Jung and Kim [32]	2022	Retrospective	Korea	Transient motor weakness (1)
Zhu et al. [33]	2022	Technical note	China	Transient paresthesia (1)
An and Lee [34]	2019	Technical note	Korea	Operation site pain and numbness (1)
Lin et al. [35]	2019	Retrospective	China	Dural tear (1)
Kim and Park [36]	2020	Retrospective	Korea	Dural tear (2), root injury (3), infection (2)
Kim et al. [37]	2020	Retrospective	Korea	Dural tear (3), hematoma (1)
Kim et al. [38]	2019	Retrospective	Korea	Transient paresthesia (5)
Kang et al. [39]	2019	Retrospective	Korea	Dural tear (1)
Kang et al. [40]	2020	Retrospective	Japan	Dural tear (2)
Kim and Choi [41]	2018	Retrospective	Korea	Dural tear (2), hematoma (1)
Hong et al. [42]	2020	Retrospective	Korea	Dural tear (2)
Heo et al. [43]	2019	Retrospective	Korea	Dural tear (1), hematoma (1)
Heo et al. [44]	2018	Prospective	Korea	Dural tear (1), hematoma (1)
Pao et al. [45]	2020	Retrospective	China (Taiwan)	Dural tear (4), transient paresthesia (1), hematoma (1), incomplete decompression (1)
Song and Lee [46]	2020	Technical note	Korea	Dural tear (1)
Fishchenko et al. [47]	2020	Retrospective	Ukraine	Dural tear (4)
Ahn et al. [48]	2018	Retrospective	Korea	Dural tear (1)
Kim et al. [49]	2018	Retrospective	Korea	Incomplete decompression (3)
Eun et al. [50]	2017	Retrospective	Korea	Incomplete decompression (1)
Torudom et al. [51]	2016	Retrospective	Thailand	Transient paresthesia (2), incomplete decompression (1)
Soliman [52]	2015	Prospective	Egypt	Dura tear (6)
Min et al. [53]	2020	Retrospective	Korea	Dural tear (2), hematoma (1)

RCT, randomized controlled trial.

UBESS reduces muscle dissection and preserves the zygapophyseal joint compared to standard open surgery. In contrast, the rate of iatrogenic spondylolisthesis after open laminectomy is reported to be between 3.96% and 9.5% [19]. Iatrogenic instability can be avoided by undercutting the facet joint. It is critical to reduce facet joint infringement during surgery to prevent postoperative instability [20,21].

## 6. Root Injury

Radiofrequency (RF) probes are essential and widely used in UBESS. However, intraoperative thermal injury from RF has been identified as the primary cause of nerve root injury [1]. While direct contact thermal injury of the nerve root by the RF probe tip can be avoided through the surgeon's skill, indirect RF thermal injury resulting from the elevation of epidural temperature may not be entirely controlled by the surgeon [22]. Heo et al. [22] reported that RF can be safely used in UBESS, and the utilization of low-power and short-duration RF can

reduce the possibility of thermal injury. Moreover, maintaining good irrigation patency in the surgical field is important for minimizing the elevation of epidural temperature caused by RF.

In UBESS, the use of a drill above the ligamentum flavum is safer than the use of a Kerrison punch to prevent root injury because ligamentum flavum can act as a barrier to protect the nerve roots during bone work.

When performing decompression at the L1/2 level, there is a possibility of spinal cord injury, particularly. Therefore, we must exercise caution to avoid compressing the thecal sac using surgical instruments such as retractors and Kerrison punches in the high lumbar segment area.

## 7. Infection

One notable aspect of UBESS is the absence of postoperative infection, which is a relatively common occurrence in conventional lumbar spinal surgery [23]. The incidence of spine infection after spine surgery ranges from approximately 0.1% to 4.5%,

with bacterial infection being the most common cause [23]. However, UBESS has a low incidence of postoperative infection due to factors such as continuous saline irrigation, shorter operation time, and reduced soft tissue injury [24].

## 8. Postoperative Headache

In UBESS, the use of high intraoperative water pressure can increase CSF pressure and intracranial pressure, leading to postoperative headaches and, in severe cases, seizures [25]. Therefore, it is important to monitor patients for symptoms such as neck pain, headaches, blurred vision, and drowsiness. To prevent the occurrence of postoperative headaches, it is crucial to control intraoperative water pressure, fluid outflow, and operation time. Choi [26] advised keeping the irrigation pump pressure below 30 mmHg. Kang et al. [27] reported that cervical epidural pressure remains within the physiological range when continuous lavage is performed with an infusion pressure set to 30 mmHg. Kim et al. [28] suggested that extending the fascia incision of the working portal would be preferable to improve fluid outflow. Czigléczi et al. [29] reported that irrigation could cause meningeal irritation and postoperative headaches, but reducing the operation time can help avoid such complications.

## 9. Retinal Hemorrhage

After a UBE discectomy, Lee et al. [30] described a patient with retinal hemorrhage. They suggested that increased CSF pressure may have been responsible for the retinal bleeding during the unilateral biportal endoscopic (UBE) discectomy procedure. This pressure could have been transmitted to the retinal venous circulation either directly through the optic nerve sheaths or indirectly through the subarachnoid extension surrounding the optic nerve. Furthermore, higher CSF pressure has the potential to reduce cerebral blood flow, triggering a reflex increase in ophthalmic artery pressure, which can lead to capillary rupture and venous collapse. According to Lee et al. [30], it is crucial to regulate the pressure of the irrigated fluid during UBE to prevent rare complications such as postoperative retinal bleeding.

## CONCLUSION

As a minimally invasive technique, UBESS has been successfully used for lumbar spine disorders and has gained popularity due to its therapeutic efficacy, including satisfactory clinical

outcomes, shorter hospital stays and operation times, and lower complication rates. Based on a literature review, the most common complications of UBESS include dural tear, epidural hematoma, nerve root injury, incomplete decompression, and postoperative headache. It is crucial to have a comprehensive understanding of the procedure, surgical technique, complications, and prevention strategies associated with UBESS.

## NOTES

### Conflicts of Interest

The authors have nothing to disclose.

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# Overview and Prevention of Complications During Full-Endoscopic Cervical Spine Surgery

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**Objective:** Posterior full-endoscopic cervical foraminotomy/discectomy (PECF) is used to treat medically intractable cervical radiculopathy. PECF has many potential advantages; however, despite its minimally invasive nature, complications of PECF are possible, including hemorrhage, infection, injury to neural tissue, damage to the facet joint and musculature, loss of cervical lordosis, and subsequent progression to cervical kyphosis. We examined complications following PECF and reviewed the relevant literature.

**Methods:** We retrospectively reviewed 101 patients who underwent PECF for either disc herniation (DH, 59 patients) or foraminal stenosis (FS, 42 patients). After surgery, the patients were encouraged to ambulate and were discharged 2–3 days later without the use of a neck collar. Events occurring during hospitalization were documented in the hospital information system. Patients were followed-up for a mean period of  $21 \pm 26$  months (range, 1–110 months).

**Results:** Clinical parameters improved from 1 month postoperatively and were maintained throughout the follow-up period, with no significant differences between the DH and FS groups ( $p > 0.05$ ). Complications occurred in 14 patients (14%) with no significant difference between the DH (8 of 59, 14%) and FS (6 of 42, 14%) groups ( $p > 0.05$ ). The most common complication was dural tear, followed by motor weakness, sensory changes, hematoma collection, incomplete decompression, reoperation, and wrong-level surgery. Two patients underwent reoperation due to symptomatic hematoma collection and symptom recurrence 3 years postoperatively.

**Conclusion:** The incidence of complications following PECF was 14%. Although most were transient, an understanding of both reported and unreported complications, along with thorough preparation, could reduce the occurrence of PECF-associated complications.

**Key Words:** Complication, Endoscopy, Minimally invasive surgical procedure, Spine, Surgery

## INTRODUCTION

Cervical spinal surgery is recommended for patients with

cervical radiculopathy and cervical central stenosis when non-surgical treatment is ineffective [1-4]. Current surgical options include anterior cervical discectomy fusion (ACDF), artificial

disc replacement, posterior microforaminotomy, biportal endoscopic posterior foraminotomy, and posterior full-endoscopic cervical foraminotomy/discectomy (PECF) [4-11]. PECF is a full-endoscopic cervical spinal surgery technique [12]. While clinical outcomes do not differ significantly among these procedures, each has inherent advantages and limitations [13]. PECF offers several potential benefits, including minimal injury to posterior spinal structures, a lower incidence of adjacent segment disease relative to ACDF, and the ability to achieve similar clinical outcomes at lower medical costs than with ACDF [14,15]. The preservation of cervical motion without instrumentation may be another advantage of PECF [13,16]. However, like all surgical techniques, PECF carries a risk of complications. The most common concern is the disruption of spinal kinematics and subsequent reoperation due to injury to the facet joint [17,18]. Nevertheless, a systematic review by Zhang et al. [19] helped alleviate this concern by demonstrating that the reoperation rate was statistically similar between PECF and ACDF (1% and 3.9%, respectively). Recent studies have shown that cervical kinematics are not as heavily disrupted by PECF as they are by open foraminotomy [20-24]. Despite the minimally invasive nature of PECF, complications are possible, including suboptimal outcomes, hemorrhage, infection, injury to neural structures, loss of cervical lordosis, and subsequent progression to cervical kyphosis [16,17,25]. Therefore, this study was designed to analyze the complications following PECF at a single center and to present an up-to-date review of publications describing PECF complications.

## MATERIALS AND METHODS

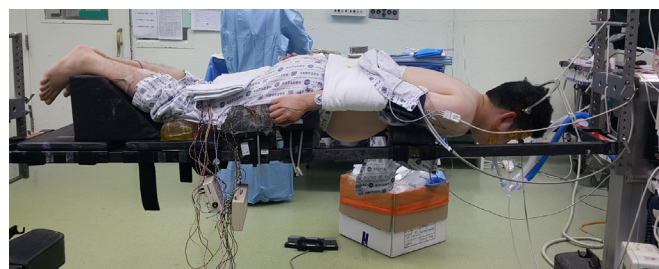
### 1. Patients

This study was approved by Seoul National University College of Medicine/Seoul National University Hospital of the Institutional Review Board (IRB No. 2101-080-1187). After receiving IRB approval, we conducted a retrospective review of patients who underwent PECF at a single institution between June 2010 and September 2022. The requirement for informed consent was waived by IRB for this retrospective study, as it posed no more than minimal risk and would not negatively impact the rights and welfare of the participants. This study included patients with (1) single- or dual-level unilateral radiculopathy due to cervical disc herniation (DH) or foraminal stenosis (FS), (2) a positive Spurling test, (3) disc space narrowing of no more than 50% [26], (4) complete preoperative clinical and radiological data, and (5) postoperative follow-up for more than 1 month

[10]. Patients were excluded if they had (1) prior cervical spinal surgery; (2) malignancy, inflammatory joint disease, trauma, psychiatric disease, or neuromuscular disease; or (3) ossification of the posterior longitudinal ligament [10,21,25,27]. For DH cases, foraminal soft DH was confirmed using computed tomography (CT) and magnetic resonance imaging in the absence of evidence of bony FS. All patients with bony FS, as confirmed by CT and magnetic resonance imaging, were classified as having FS. In total, 101 patients (59 with DH and 42 with FS) were included in this study.

### 2. Surgical Techniques

The surgical techniques for PECF were consistent with those previously reported [10,20-23,25,28-30]. PECF was performed with the patient in the prone position under general anesthesia (Figure 1). The surgical level was identified using C-arm fluoroscopy, and an 8-mm skin incision was made above the "V-point," which is formed by the lamina, descending facet, and ascending facet [10,20-23,25,29,30]. A dilator (6.9-mm outer diameter), working channel (8.0-mm outer diameter), and endoscope (Vertebri, 4.1-mm working channel; Richard Wolf GmbH, Knittlingen, Germany) were sequentially introduced through the skin incision (Figure 2) [10,20-23,25,29,30]. Laminectomy and facetectomy were performed using an endoscopic drill under direct visualization. The size of bone drilling depended on the size and location of the herniated disc material and the extent of stenosis, typically within a radius of 3-4 mm around the V-point for soft DHs and 5-6 mm for FS [20-23,25]. Decompression and free movement of the nerve root were confirmed at the level of the shoulder/axilla and the



**Figure 1.** Patient positioning. Surgery is performed with the patient in the prone position under general anesthesia. Gardner-Well tong skeletal fixation is utilized to facilitate the procedure. Careful attention is paid to ensure that the abdomen can freely sag, as this is important to reduce epidural venous congestion and bleeding.

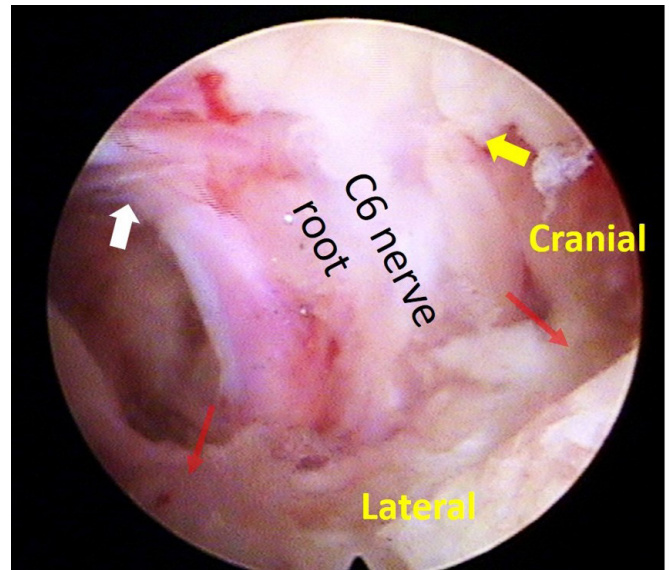


**Figure 2.** Surgeon's working position. After introducing the spinal endoscope through an 8-mm skin incision, the surgeon holds the endoscopic system. The grip posture is discretionary, but to minimize fatigue during surgery, the arm should not be raised above the shoulder.

superolateral/inferolateral corner of the nerve root (**Figure 3**) [10,20,22,25,29,30]. A closed-suction drain was inserted through the working tube, and the skin was closed (**Figure 4**). Patients were encouraged to walk on the day of surgery without a neck brace and were discharged the following day without limitations on neck motion [21,25].

### 3. Clinical Evaluations

Any events that occurred during hospitalization were documented in the hospital information system. Patient-reported outcome measures included the Neck Disability Index (scored out of 50) [31] as well as numerical rating scores for neck pain (NRS-N, out of 10) and arm pain (NRS-A, out of 10). These measures were evaluated before surgery and during outpatient



**Figure 3.** Nerve root decompression. Intraoperative photo demonstrates a decompressed C6 nerve root. Decompression and unimpeded motility of the nerve root are confirmed at the level of the shoulder/axilla (indicated by the yellow/white arrow) and the superolateral/inferolateral corner (marked by the red arrow) of the nerve root.

clinic visits at 1, 3, 6, and 12 months postoperatively, as well as yearly thereafter. Patients were followed-up for an average of  $21 \pm 26$  months (range, 1–110 months).

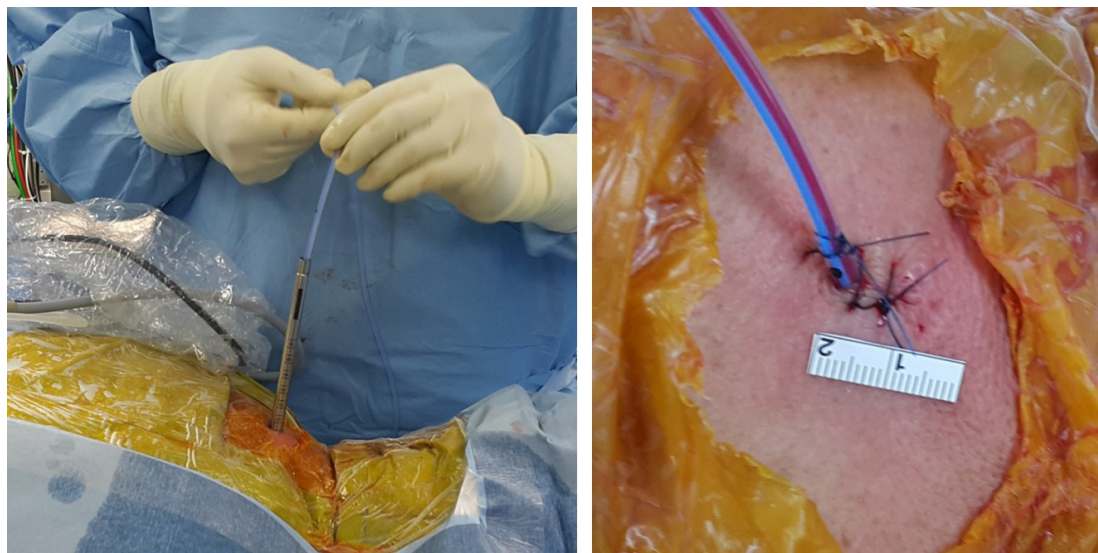
### 4. Statistical Analysis

The patients were divided into 2 groups: DH (n=59) and FS (n=42), with variables summarized as either mean (standard deviation) or frequency (proportion). The presence of any complications was assessed. Clinical outcomes were compared between the groups using the t-test at each time point. All analyses were performed using IBM SPSS Statistics ver. 26.0 (IBM Co., Armonk, NY, USA). A 2-tailed p-value of less than 0.05 was considered to indicate statistical significance.

## RESULTS

The most common surgical level was C6–7, followed by C5–6 (**Table 1**). In 99 patients, the procedure was single-level, while in 2 patients, it was 2-level. Clinical parameters demonstrated immediate improvement from 1 month postoperatively, and these improvements were sustained throughout the follow-up period (**Table 2**, **Figure 5**). No significant difference in clinical improvement was observed between the DH and FS groups ( $p > 0.05$ ). Complications arose in 14 patients (14%), with no





**Figure 4.** Closed-suction drain placement. A silastic drain is inserted through the working channel of the endoscopic system and is typically removed on postoperative day 1.

**Table 1.** Characteristics of patients

Characteristic	Total	DH	FS
Age (yr)	50.2 ± 10.4	47.7 ± 11.0	53.7 ± 8.3
Sex, male:female	68:33	34:25	34:8
Level			
C3–4	1	1	0
C4–5	5	3	2
C4–6*	2	1	1
C5–6	33	19	14
C5–7*	1	0	1
C6–7	49	28	21
C6–T1*	1	1	0
C7–T1	9	6	3
NDI (/50)	22.6 ± 8.1	23.2 ± 8.6	21.9 ± 7.4
NRS–N	6.1 ± 2.3	6.3 ± 2.1	5.8 ± 2.5
NRS–A	7.1 ± 1.8	7.2 ± 2.0	6.9 ± 1.5
Complication			
Dura tear	4	2	2
Sensory†	2	2	0
Motor†	3 <sup>‡</sup>	2 <sup>‡</sup>	1
Hematoma	2 <sup>‡</sup>	1 <sup>‡</sup>	1 (no reoperation)
Incomplete	2	1	1
Wrong level	1	1	0
Reoperation	2 <sup>‡</sup>	1 <sup>‡</sup> (hematoma)	1 (recurrent symptom)

Values are presented as mean ± standard deviation or number.

DH, disc herniation; FS, foraminal stenosis; NDI, neck disability index; NRS–N, Numerical Rating Scale for neck pain; NRS–A, Numerical Rating Scale for arm pain.

Age:  $p=0.004$  (There was a statistically significant age difference between patients who suffered from disc herniation and those that suffered from foraminal stenosis).

\*Two-level surgery. †A sensory complication refers to subjective deterioration of paresthesia/hypoesthesia after surgery. A motor complication refers to subjective and clinical deterioration of motor power, assessed with the Manual Muscle Testing grade scale. ‡Counted for each event in one patient.

significant difference in the complication rate between the DH group (8 of 59 patients, 14%) and the FS group (6 of 42 patients, 14%) ( $p>0.05$ ) (Table 1). The most common complication was dural tear, followed by motor weakness, sensory changes, hematoma collection, incomplete decompression, reoperation, and wrong-level surgery (Table 1). Reoperation was performed in 2 patients due to symptomatic hematoma collection and symptom recurrence 3 years after surgery. Asymptomatic postoperative hematomas were closely monitored without sequelae. Although intraoperative dural tear occurred in 4 patients, the tears were minimal, and the arachnoid membrane remained intact. Consequently, the surgical wounds were closed without repairing the dura or applying an artificial dural patch. One patient experienced severe C6 nerve root palsy (Manual Muscle Testing grade 2 after surgery), likely due to an intraoperative bed hematoma. The hematoma was evacuated at the operative site, but motor weakness did not immediately resolve, and full recovery took 12 months. The other case of transient weakness (Manual Muscle Testing grade 4+ or 5) resolved within 1 month.

## DISCUSSION

The aim of this study was to examine complications following PECSF and review the current literature on its complications. Our findings revealed a complication rate of 14%, with no significant difference between the DH and FS groups. These



**Table 2.** Clinical outcomes

Variable	Pre	1 Month	3 Months	6 Months	12 Months	24 Months
NDI						
Total	22.6 ± 8.1	9.0 ± 5.7	7.0 ± 5.3	7.2 ± 5.4	6.1 ± 7.1	3.9 ± 6.4
DH	23.2 ± 8.6	8.7 ± 5.9	5.8 ± 4.8	6.5 ± 5.2	4.2 ± 5.0	2.8 ± 4.6
FS	21.9 ± 7.4	9.7 ± 5.3	8.3 ± 5.7	8.4 ± 5.8	9.7 ± 9.0	7.1 ± 9.5
NRS-N						
Total	6.1 ± 2.3	2.1 ± 1.7	1.4 ± 1.7	1.5 ± 1.7	1.3 ± 1.6	0.9 ± 1.5
DH	6.3 ± 2.1	2.1 ± 1.7	1.2 ± 1.3	1.2 ± 1.4	1.2 ± 1.7	0.7 ± 1.3
FS	5.8 ± 2.5	1.9 ± 1.7	1.7 ± 2.0	2.0 ± 2.0	1.5 ± 1.5	1.5 ± 2.0
NRS-A						
Total	7.1 ± 1.8	2.5 ± 1.8	1.8 ± 1.6	1.7 ± 1.4	1.7 ± 2.0	1.1 ± 1.5
DH	7.2 ± 2.0	2.3 ± 1.7	1.5 ± 1.4	1.6 ± 1.4	1.4 ± 1.8	1.2 ± 1.7
FS	6.9 ± 1.5	3.0 ± 2.0	2.3 ± 1.9	1.8 ± 1.5	2.4 ± 2.3	0.9 ± 1.1

Values are presented as mean ± standard deviation.

DH, disc herniation; FS, foraminal stenosis; NDI, neck disability index; NRS-N, numerical rating scale for neck pain; NRS-A, numerical rating scale for arm pain.

results suggest that the risk associated with the surgical procedure is similar across different pathologies.

## 1. Complications of PECF

Zhang et al. [19] conducted a systematic review indicating a 3% complication rate for PECF (95% confidence interval [CI], 1%–5%), which was lower than that of ACDF at 7.79% (95% CI, 5.54%–10.85%) ( $p < 0.05$ ). PECF has often been compared with endoscopy-assisted spinal surgery, specifically microendoscopic foraminotomy (MEF). In a separate systematic review, Wu et al. [32] revealed overall complication rates of 5.8% for PECF and 3.5% for MEF ( $p = 0.12$ ). Although these overall rates were similar between the procedures, transient root palsy was the most common complication after PECF (80%), while dural tear was the most common after MEF (42%) [32]. The rates of complications such as dural tear (PECF, 1.5%; MEF, 1.8%;  $p = 0.67$ ) and superficial wound infection (PECF, 2.2%; MEF, 1.0%;  $p = 0.11$ ) were not significantly different between groups [32].

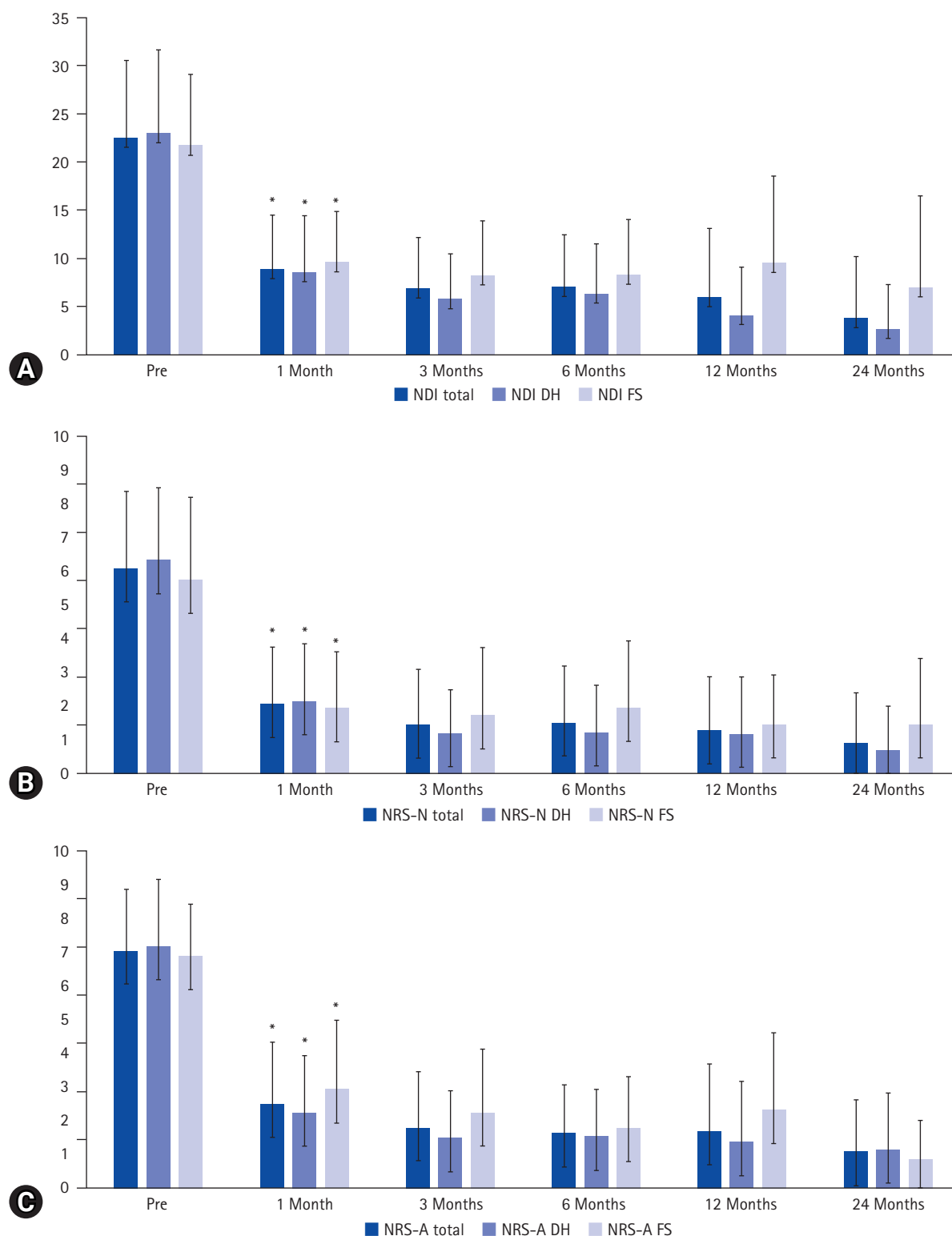
## 2. Suboptimal Clinical Outcomes

A frequently expressed concern regarding PECF is the potential for insufficient decompression and suboptimal outcomes. This concern may be valid, given the limited surgical view and instruments available. As demonstrated in this study, insufficient decompression occurred in the early stages of PECF (in the years 2015 and 2017) for 2 patients; however, reoperation was not performed due to substantial symptom improvement.

Recent advances in optics and surgical instruments have helped to address this concern. As shown in Figure 3, complete decompression of the nerve root is now achievable, as recommended in standard surgical techniques [8,33,34]. The present study revealed that clinical outcomes had significantly improved by postoperative month 1 and were maintained for 2 years. Lv et al. [35] conducted a systematic review and found that both PECF and MEF resulted in substantial improvements in clinical outcomes, with no differences between the surgical techniques. Zhang et al. [19] compared PECF and ACDF and found no significant differences in the improvement of clinical outcomes, such as pain and Neck Disability Index, between procedures. Lee et al. [29] analyzed the recovery of preoperative weakness following PECF. In patients with mild weakness, normalization rates were 48%, 81%, 90%, and 96% at postoperative months 1, 3, 6, and 12, respectively. In patients with severe weakness, the improvement rates were 50%, 71%, 83%, 88%, and 92%, while the normalization rates were 8%, 38%, 58%, 58%, and 63% at postoperative months 1, 3, 6, 12, and 24, respectively [29]. These findings support the possibility that sufficient decompression can be achieved with PECF.

## 3. Reoperation

Another concern was the higher reoperation rate after posterior foraminotomy relative to that of ACDF. Lubelski et al. [36] analyzed matched cohorts and reported a reoperation rate of 6.4% at the index level after posterior open cervical foraminotomy and 4.8% after ACDF during a 2-year postoperative follow-up ( $p = 0.07$ ). A systematic review in 2019 showed similar



**Figure 5.** Clinical outcomes. By 1 month postoperatively, significant improvements were demonstrated in the Neck Disability Index (NDI, scored out of 50) (A), Numeric Rating Scale for neck pain (NRS-N) (B), and Numeric Rating Scale for arm pain (NRS-A) (C), with these improvements sustained throughout the follow-up period. No significant difference was observed between the disc herniation (DH) and foraminal stenosis (FS) groups. An asterisk (\*) indicates statistical significance ( $p < 0.05$ ).

reoperation rates (3.9% vs. 6.9%) and complication rates (7.8% vs. 4%) between ACDF and minimally invasive posterior cervical foraminotomy [6]. Despite the lack of statistical significance, the higher reoperation rate after posterior foraminotomy has been a concern. The present study showed that secondary surgery was necessary for one patient (1%) at the index level. Zhang et al. [19] analyzed the reoperation rate after PECF in a systematic review and found that it was not significantly different between PECF (1%) and ACDF (3.9%). Although PECF is a minimally invasive surgical technique, it is not a regenerative treatment; thus, degeneration may naturally progress by 2 years postoperatively, as shown in this study. However, the incidence was significantly lower than that of ACDF, suggesting the benefit of a minimally invasive surgical technique [8,11,19,34,37]. Biportal endoscopic surgery has recently received attention due to the comfortable transition from open surgery to this new procedure. In the near future, the effect of minimally invasive biportal cervical endoscopic surgery may be compared with that of PECF in a prospective study [8,11,38-41].

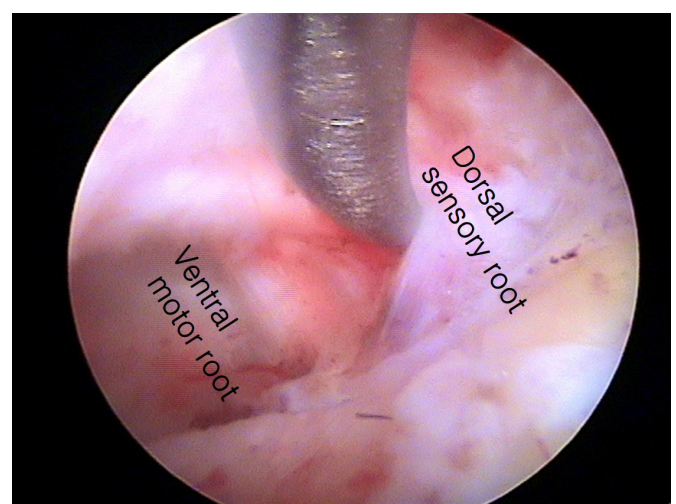
#### 4. Neurological Injury

Zhang et al. [19] conducted a systematic review and found that transient paresthesia was the most common complication after PECF (9 of 486, 1.8%), but it resolved over time. In the present study, sensory changes occurred in 2 patients after surgery, but these symptoms were managed with pregabalin for 1 month. The causes of paresthesia were multifactorial, potentially resulting from surgical trauma, thermal injury, or secondary changes after decompression. Motor weakness after posterior foraminotomy was not an uncommon complication and also occurred after PECF. In a systematic review, motor weakness was observed in 7 of 486 patients (1.4%), while in the present study, it occurred in 2% of patients [19]. Zhang et al. [19] reported that minor motor weakness (found in 3 patients) recovered after 3 months, while severe motor weakness was found in 4 patients and improved after 12 months. Motor weakness typically occurred due to excessive retraction of the nerve root [42]. Additionally, although it was not emphasized, a dual nerve root was detected in 20% of patients during surgery (Figure 6) [23,43]. The relative location of the nerve root over the disc space (the axilla of the nerve root in the lower cervical spine and the shoulder of the nerve root in the upper cervical spine) and the presence of dual roots should be considered to minimize nerve root injury [42]. A systematic review stated that dural injury occurred in 2 of 486 patients (0.4%), even though it was not a major focus of the study [19]. Uncertainty exists re-

garding whether repairing a torn dura is necessary during PECF, given the limited surgical instruments available for dural repair. In the current study, dural tear was the most common complication, but no patient required a second operation due to problems associated with cerebrospinal fluid leakage. Although the evidence is not robust, during PECF surgery, muscle is not resected but rather is split. After the removal of the working channel at the end of surgery, the muscles close by themselves [44]. This self-closure of the muscles may prevent cerebrospinal fluid leakage through the surgical wound. Another issue is intracranial hypotension, but this did not occur in the present study, possibly due to the space being too small to cause intracranial hypotension. However, a small amount of hematoma collection may cause neurological injury, as demonstrated in this study. Zhang et al. [19] showed that hematoma collection occurred in 2 of 486 (0.4%) patients after PECF in a systematic review. Therefore, closed-suction drainage may be helpful in preventing the collection of symptomatic hematoma at the surgical site (Figure 4), if necessary. To prevent neurological injury, careful manipulation of neural tissue, judicious use of surgical instruments and coagulators around neural tissue, and the insertion of closed suction, if necessary, are required [45].

#### 5. Intraoperative Seizure

Although increased intracranial pressure was not emphasized in a systematic review or the previous literature, unnoticed elevated epidural pressure may have catastrophic consequences [46]. While not reported during PECF, including in the



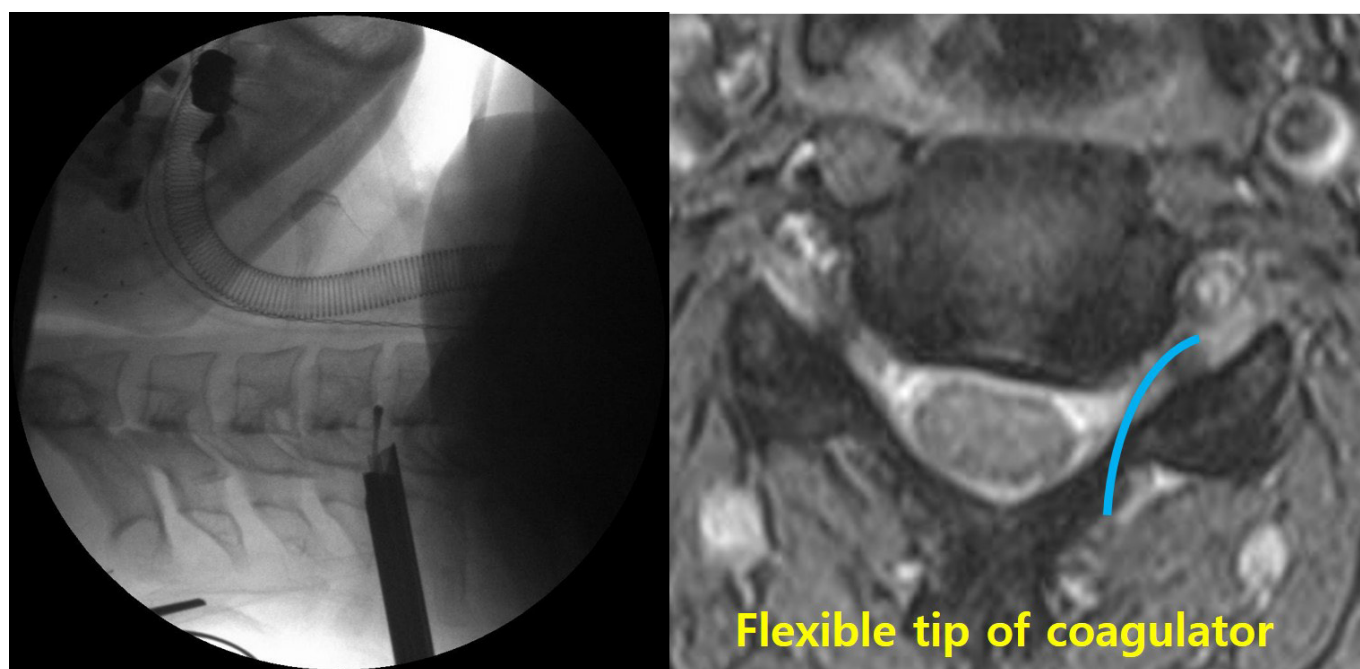
**Figure 6.** Dual nerve root. The ventral motor root is visible after retraction of the dorsal sensory root.

present study, seizures have been reported in 3 of 816 patients (0.34%) during fully endoscopic lumbar surgery [46]. PECF is performed in water to create a surgical space and to wash out blood and surgical debris. These factors contribute to the advantages of PECF in minimizing soft tissue injury and post-operative infection, but the issue of water pressure remains. Increased epidural pressure may directly or indirectly damage the spinal cord or cause intracranial hypertension [46,47]. Joh et al. [48] demonstrated that indirectly transmitted increased epidural pressure from the lumbar spine to the cervical spine elicited neck pain, with the pressure at the neck averaging 53 mmHg (721 mmH<sub>2</sub>O). Although the exact mechanism of seizures during fully endoscopic spine surgery is still undetermined, factors such as infusion fluid containing cefazolin, infusion rate, prolonged operative time, dural tear, and sevoflurane anesthesia may increase the risk of seizures [46]. Symptoms and signs, such as headache, neck pain, seizures, elevated blood pressure, or bradycardia, should be carefully monitored in patients [49,50]. Lin et al. [46] reported the cases of seizures during full-endoscopic lumbar surgery and found that a so-called red flag sign—characterized by uncontrollable hypertension combined with a decreasing pulse rate—occurred in all 3 patients who experienced a seizure. Although not definitively established, this phenomenon bears similarity to the Cushing reflex, a cardiovascular response to compensate for increased

intracranial pressure. This reflex sometimes occurs during endoscopic brain surgery, wherein the working space inside the brain is maintained with infused water pressure [49,50]. Previously, when a dural tear occurred during fully endoscopic spine surgery, 3 of 15 patients experienced seizures, and 1 of the 3 patients exhibited intracranial air on a postoperative CT scan [50]. Thus, strict control of epidural pressure is required when a dural tear occurs during surgery. The water pressure through the endoscopic system should be kept below 70 cmH<sub>2</sub>O by irrigating with saline using gravity or via careful use of a water irrigation pump to prevent increased intracranial pressure and unexpected intraoperative seizures [48,49].

## 6. Vertebral Artery Injury

Due to the proximity of the vertebral artery to the neural foramen, the artery may be injured during surgery. While no research is available on this specific complication, the authors have observed several cases of vertebral artery injury and subsequent infarction in the cerebellum and/or medulla oblongata at academic conferences. During the surgical procedure, a flexible coagulator may inadvertently enter the vertebral foramen (Figure 7), and an unnoticed injury caused by compression, coagulation, or vascular spasm may result in a vascular accident.



**Figure 7.** Potential risk of vertebral artery injury. Passage of the flexible electrode through the foramen to reach the vertebral artery, situated between the vertebral foramina, can result in vertebral artery injury.



## 7. Radiological Changes

Jagannathan et al. examined the segmental and cervical angles following posterior open cervical foraminotomy, finding a loss of cervical lordosis in 20% of patients (30 of 162), with one-third of these patients experiencing symptoms [17]. Despite this limitation, posterior cervical foraminotomy has been widely accepted as a valid surgical procedure for patients with radiculopathy, demonstrating a similar reoperation rate to that of anterior cervical discectomy and fusion [5,6,9,11,13,17,19,33,36,43,51,52]. PECF has recently emerged as an alternative to microscopic surgery, displaying comparable clinical outcomes in randomized controlled trials and systematic reviews [5,6,9,11,13,17,19,23,33,36,43,51,52]. The primary advantage of PECF lies in its minimally invasive nature, which can be attributed to the high magnification and illumination [25]. The resection of the facet joint involved removal of less than 10% of the joint's original size (Figure 8) [25]. As a result, these benefits were evident in the improved cervical lordosis observed after PECF, even in patients with cervical hypolordosis [20,21], as well as in the preservation of cervical kinematics [10,22].

## 8. Limitations

While we attempted to address various reported and poten-

tial complications of PECF in this study, we acknowledge its limitations. First, the sample size was not large enough to establish a generalized consensus. The incidence of complications depends on each surgeon's surgical technique and expertise. Second, this study was impacted by selection bias, as it did not include patients with severe cervical degeneration. The unique characteristics of severe degeneration, such as hypertrophied facet joints and perineural adhesion, were not considered in this study. These factors may have influenced the outcomes, including complications. Third, although this study involved a review of previous literature, it was not a systematic review. Finally, this study did not address long-term complications other than reoperation. The long-term effects of PECF on cervical degeneration and kinematics must be examined to improve surgical techniques. Despite these limitations, we have endeavored to discuss all types of reported and unreported complications of PECF in this manuscript. This information may be helpful in reducing complications associated with PECF.

## CONCLUSION

The incidence of complications following PECF was 14%. Although the majority of these complications were transient, an understanding of both reported and unreported complications, along with thorough preparation, could help reduce the occurrence of complications associated with PECF.

## NOTES

### Conflicts of Interest

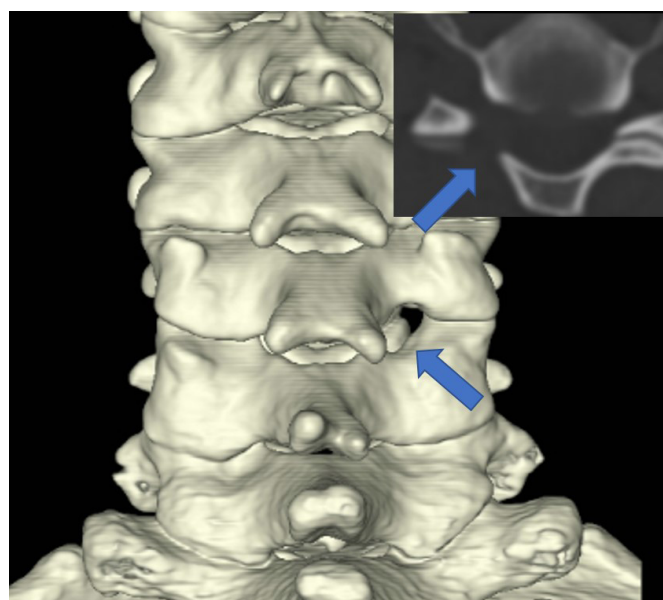
The last author (CHK) is a consultant of RIWOspine. The other authors have nothing to disclose.

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**Figure 8.** Postoperative computed tomography illustrates the typical extent of endoscopic foraminotomy. The facet joint resection involves removing less than 10% of the joint's original size. Blue arrow: site and extent of cervical endoscopic foraminotomy.

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# Overview and Prevention of Complications During Biportal Endoscopic Thoracic Spine Surgery

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**Objective:** Although the unilateral biportal endoscopy (UBE) technique has remarkable advantages, thoracic laminectomy by UBE is technically difficult and can potentially lead to serious complications. By reviewing previous articles on thoracic laminectomy by UBE, we aimed to identify the complications of thoracic laminectomy by UBE and to establish specific surgical strategies to avoid complications.

**Methods:** A literature search was performed using the National Center for Biotechnology Information database using the PubMed/MEDLINE search engine. There are 3 published clinical studies in which at least one of these approaches has been performed.

**Results:** In previous articles, several cases of perioperative complications were observed, including spinal cord injury, hyperalgesia, cerebrospinal fluid leakage, headache or neck pain, insufficient decompression, epidural hematoma, subdural hematoma, excessive facet resection, and delayed spinous process fracture.

**Conclusion:** UBE technique has remarkable advantages, but endoscopic thoracic surgery is technically challenging and has the potential to cause serious complications. For avoidable complications, surgeons should be familiar with prevention methods and pitfalls to minimize complications.

**Key Words:** Endoscopy, Laminectomy, Ligamentum flavum, Spinal stenosis, Thoracic surgery

## INTRODUCTION

Conventional thoracic laminectomy is the operative treatment for thoracic ossified ligamentum flavum (OLF) or thoracic spinal stenosis [1,2]. However, its clinical outcome is frequently disappointing and often accompanied with complications [3,4]. In a conventional thoracic laminectomy, postoperative complications, including iatrogenic spinal cord injury, dural tear, and postoperative infection, are relatively common [5]. Moreover, it has disadvantages, such as paraspinal muscle atrophy and back pain caused by posterior paraspinal muscle dissection [4,6].

As a result, many alternative surgical techniques were developed, including thoracic decompression with endoscopic guidance [7-13]. Recently, thoracic laminectomy by unilateral biportal endoscopy (UBE) was developed and described by a few studies [7-9]. It demonstrated several advantages as compared to conventional thoracic laminectomy and has been shown to have favorable clinical outcomes [7,9]. Although the UBE technique has remarkable advantages, thoracic laminectomy by UBE is technically difficult and can potentially lead to serious complications.

By reviewing previous articles on thoracic laminectomy by

UBE, we aimed to identify the complications of thoracic laminectomy by UBE in patients with thoracic OLF or thoracic spinal stenosis and to establish specific surgical strategies to avoid complications. Furthermore, we sought to demonstrate the indications for thoracic laminectomy by UBE and to discuss the surgical techniques.

MATERIALS AND METHODS

Eligible studies included in which patients underwent thoracic laminectomy by UBE due to thoracic OLF or thoracic spinal stenosis. Inclusion criteria were studies of human subjects published in the English language. Studies that did not include clinical outcomes or postoperative complications as outcome variables were excluded. Abstracts, case reports, editorials and expert opinions were excluded. Criteria used in this review for article selection were: (1) surgically managed thoracic pathology using UBE techniques, (2) average follow-up period no less than 1 year, (3) pertaining to postoperative complication.

A literature search was performed using the National Center for Biotechnology Information database using the PubMed/MEDLINE search engine. The keywords used in this search were “unilateral biportal endoscopy,” “thoracic,” and “biportal.” The Medline and Scopus databases were used to identify relevant studies published in English. While reviewing the literature, articles on endoscopic thoracic spine surgery were retrieved through the abovementioned search. We emphasize ways to avoid and manage the approach-related morbidity. There are 3 published clinical studies in which at least one of

these approaches has been performed (Table 1). Table 2 summarizes the surgery-related complications reported in a series of trials.

The indications and contraindications for thoracic laminectomy by UBE are as follows [7-9]: (1) thoracic OLF and (2) thoracic spinal stenosis. The contraindications of thoracic laminectomy by UBE are as follows: (1) soft or calcified disc herniation, (2) severe ossified posterior longitudinal ligament, (3) spinal column instability, and (4) high-grade deformity.

RESULTS

Three articles reported on posterior thoracic decompression by UBE (Table 1) [7-9]. The overall complications associated with thoracic laminectomy by UBE are shown in Table 2. The first article was a previous technical article that described about the OLF’s removal by UBE technique [8]. The other 2 articles presented the surgical techniques and described preliminary clinical outcomes [7,9]. Deng et al. [7] described posterior thoracic decompression by UBE in 14 patients with 1-level thoracic OLF. They presented favorable clinical outcomes in terms of thoracic decompression by UBE with an average follow-up of 15.4 months. Five cases of perioperative complications were noted (1 patient with cerebrospinal fluid leakage [CSF, 7.1%], 2 with headaches and neck pain [14.3%], and 2 with hyperalgesia of lower limbs [14.3%]). One patient with CSF was treated by maintaining a prone position for 5 days. Headache and neck pain happened in 2 patients, which disappeared in 2 days. Hyperalgesia of the lower limbs in 2 patients was relieved after

Table 1. Summary of the included studies on thoracic laminectomy by unilateral biportal endoscopy

Study	Study design	No. of patients	Age (yr)	Follow-up (mo)	Operative time (min)	Operative level
Deng et al. [7] 2022	Case control	UBE :14	59.4 ± 9.3	15.4 ± 2.8	66.1 ± 15.4	Single
		Open: 45	56.2 ± 6.7	37.0 ± 14.4	125.0 ± 29.9	
Kang et al. [8] 2022	Technical note	NA	NA	NA	NA	Single
Kim et al. [9] 2023	Case series	UBE: 16 (single: 16, two: 5)	60.4 ± 9.7	17.4 ± 4.4	106.6 ± 38 (each level)	Single, two

Values are presented as mean±standard deviation.  
NA, not applicable; UBE, unilateral biportal endoscopy.

Table 2. Complications reported in thoracic laminectomy by unilateral biportal endoscopy

Study	No. of patients	Spinal cord injury	Hyperalgesia	CSF leakage	Head,neck pain	Insufficient decompression	Epidural hematoma	Subdural hematoma	Excessive facet resection	Delayed spinous process fracture
Deng et al. [7] 2022	14	-	2	1	2	-	-	-	-	-
Kim et al. [9] 2023	16	2	-	-	-	1	1	1	1	3

CSF, cerebrospinal fluid.

conservative treatment in 1–3 weeks.

Kim et al. [9] described posterior thoracic decompression by UBE in 16 patients with single (11 cases) or 2-level (5 cases) thoracic OLF. Nine cases of perioperative complications were observed, including 2 cases of cord injury, 1 case of insufficient decompression, 1 case of subdural hematoma, 1 case of epidural hematoma, 3 cases of delayed spinous process fracture, and 1 case of facet joint violation. Of the 2 patients with iatrogenic cord injury, 1 patient recovered quickly, whereas the other patient did not improve and required assistance in ambulation at the last follow-up. Two patients had subdural and epidural hematoma, which were managed by conservative treatment. Excessive facet resection in 1 patient and spinous process fracture in 3 patients happened at the T2–3 and T3–4 levels; however, these complications did not cause mechanical back pain and segmental instability during the follow-up duration.

### 1. Dural Tear

Dural tear is the most common complication of thoracic OLF removal, especially when the case has a dural ossification [4,14]. In a series of 14 cases by using the UBE technique, Deng et al. [7] demonstrated one case of CSF leakage (7.1%). Kim et al. [9] also described no case of CSF leakage in their series of patients treated by UBE, which differs from the data reported in previous studies.

### 2. Postoperative Hematoma

Uncontrolled epidural bleeding might cause symptomatic epidural hematoma, which sometimes requires revision surgery. In a series of 16 cases, Kim et al. [9] reported one case of epidural hematoma, which was managed by conservative treatment.

### 3. Iatrogenic Cord Injury

Iatrogenic cord injury is another serious complication of thoracic surgery both in endoscopic and conventional surgeries [15]. The manipulation of the thoracic spinal cord with endoscope or instruments raised the risk of cord injury; therefore, thoracic laminectomy should be performed with caution to avoid mechanical injury. In thoracic laminectomy by UBE, the procedure could be related to cord injury by the use of an endoscope or surgical instruments and thermal injury generated by the overuse of the radiofrequency (RF) probe. In a previous report, 2 patients developed hyperalgesia, which was relieved

after conservative treatment for 1–3 weeks [7]. Similarly, Kim et al. [9] reported 2 complications of cord injury in a patient who had undergone thoracic laminectomy by UBE. They mentioned that the “inside-out piecemeal removal of OLF” method could repeatedly cause mechanical injury to the spinal cord, leading to iatrogenic spinal cord injuries.

### 4. Water-Induced Complications

The poor outflow of saline irrigation will raise the intracranial pressure, which can cause water-induced complications, including neck stiffness, headache, seizures, and iatrogenic cord injury [7-9,16].

### 5. Other Complications

The other complications included postoperative spinous process fracture and excessive facet resection. Kim et al. [9] reported on cases of a spinous process fracture and excessive facet resection following a thoracic laminectomy by UBE. The upper thoracic vertebrae have relatively smaller lamina, facet joints, and short spinous processes. Therefore, during bilateral decompression from the unilateral side of the upper thoracic level, the preservation of the spinous process and the contralateral lamina may be technically more challenging [9]. Although spinous process fracture does not occur immediately after surgery, delayed spinous process fractures can occur as the thinned bone is subjected to continuous mechanical stress. However, these complications did not cause mechanical back pain and segmental instability during the follow-up period. Given that the posterior musculo-ligamentous complex could be preserved using the UBE technique, complications, such as mechanical pain or postoperative instability, are thought to be mild.

## DISCUSSION

The thoracic laminectomy by UBE has the following distinct advantages over the conventional surgery for thoracic pathology: (1) the UBE technique may provide appropriate decompression with minimal musculoligamentous injury or facet joint violation [7,9]; (2) the endoscope and various instruments could be moved independently, which makes the procedure more comfortable and easy as compared to other endoscopic procedures [17]; and (3) surgery can be performed under a highly magnified and clear operative view with saline irrigation [18]. Therefore, UBE technique can achieve exact thoracic decom-

pression while lowering the risk of complications.

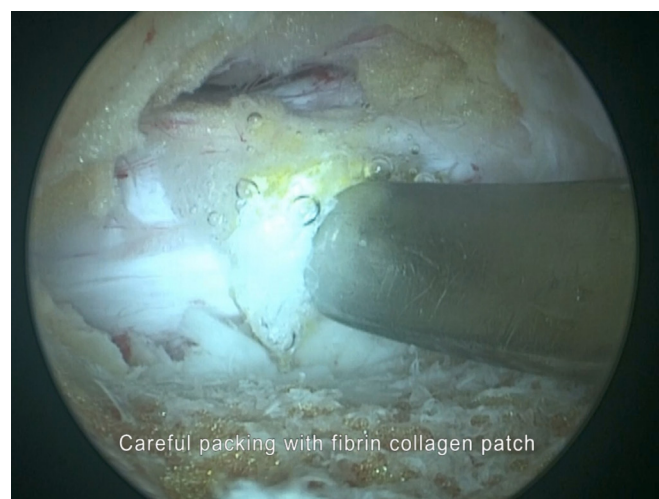
Based on the results of 2 previous studies, thoracic laminectomy by UBE may be associated with fewer potential complications [7,9]. Severe water-related complications, including epidural fluid collection and raised intracranial pressure, were not observed. However, these studies have some limitations. Firstly, severe OLF cases, such as tuberous-type OLF or severe dural ossification, might be excluded, that may cause a bias of complications. Second, 2 studies evaluated the clinical outcomes based on the results obtained within the 2-year follow-up.

The management of dural tear is well known, which typically involves a combination of fibrin collagen patch (TachoComb, CSL Behring, Tokyo, Japan) and bedrest of 3–5 days (Figure 1) [18]. However, when the dural tear is too large that the fibrin collagen patch cannot cover it, conventional surgery should be performed to perform dural suturing; subsequently, a lumbar drain could be placed. The severe adhesion of the OLF to the dura sac or dural ossification, which has a high risk of dural tear, is a complication. Preoperative CT combined with MRI should be examined for the presence of dural ossification with the dural matter to prevent this complication. In such cases, it is suggested that a thinned calcified lesion be left against the dural sac.

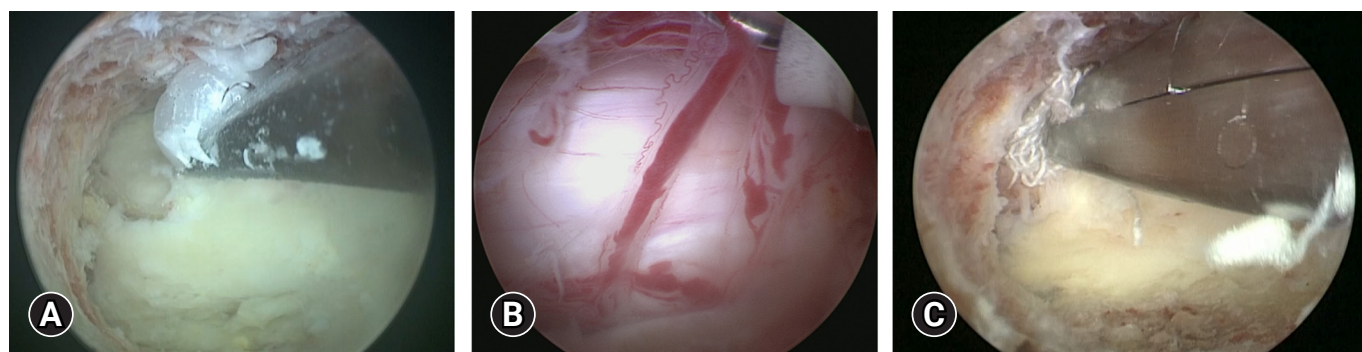
To prevent postoperative hematoma when performing thoracic laminectomy by UBE, some principles should be pursued. Bleeding from the removed bone surface should apply bone wax to prevent the risk of hematoma (Figure 2A). Prior to Ligamentum flavum (LF) resection, the use of the RF probe and hemostatic agents (Gelfoam [Gelfoam, Pharmacia & Upjohn, Kalamazoo, MI] or Wound Clot [Core scientific creations, Israel]) is effective to control bleeding. Focal epidural bleeding from the epidural vessel can be controlled by using an RF probe

(Figure 2B). For epidural bleeding whose bleeding focus is not clear, the use of hemostatic agents (Gelfoam or WoundClot) could be helpful (Figure 2C). To reduce the risk for postoperative hematoma, the use of a Jackson-Pratt surgical drain (100 mL) is recommended to be placed through the working portal for 1 or 2 days.

Since the thoracic cord is vulnerable to mechanical compression, thoracic laminectomy by UBE should be performed carefully to prevent iatrogenic spinal cord injury. The prevention of iatrogenic cord injury is based on several recommendations, which are as follows: (1) when bone working is achieved, care should be taken to protect the thoracic spinal cord while saving the LF; (2) removal of the base of the spinous process should be required to obtain an unobstructed view and to assist in positioning the scope and instruments at the contralateral side;

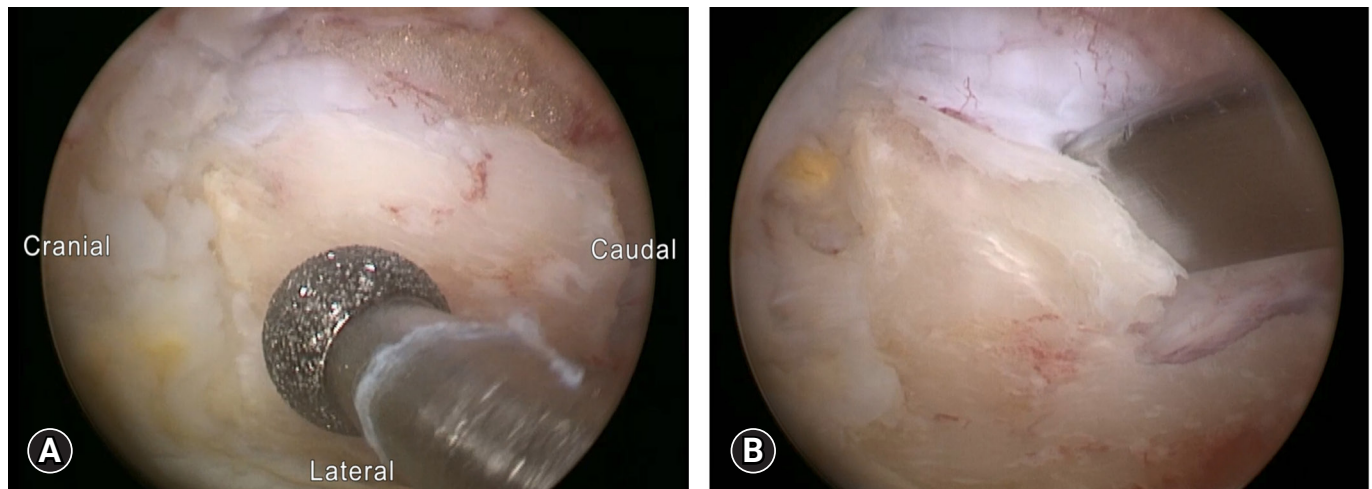


**Figure 1.** The management of dural tear by fibrin collagen patch (TachoComb, CSL Behring, Tokyo, Japan).



**Figure 2.** Bleeding control when performing thoracic laminectomy by unilateral biportal endoscopy. (A) Bleeding from the removed bone surface should apply bone wax to prevent the risk of hematoma. (B) Focal epidural bleeding from the epidural vessel can be controlled by using an radiofrequency probe. (C) For epidural bleeding whose bleeding focus is not clear, the use of hemostatic agents (Gelfoam or WoundClot) could be helpful.





**Figure 3.** The prevention of iatrogenic cord injury in thoracic laminectomy by unilateral biportal endoscopy. (A) It is recommended to thin the ossified ligamentum flavum (OLF) with a diamond burr through the OLF into a translucent type. (B) The paper-thin OLF can be safely detached with a Freer elevator.

(3) it is recommended to thin the OLF with a diamond burr through the OLF into a translucent type (Figure 3A). The paper-thin OLF can be safely detached with a freer elevator or fine pituitary forceps, and its removal reduces the risk of additional neural injury (Figure 3B); (4) if removing the OLF is dangerous due to dural ossification or severe adhesion, it is recommended to remain the thinned OLF. The dural defect should be thoroughly applied with a fibrin collagen patch after the OLF has been floated; and (5) intraoperative electrophysiological monitoring is required to detect iatrogenic spinal cord injury during operation [9].

The reported water-related complications were minor; however, serious complications could be possible. Therefore, it is necessary to monitor the fluid output and complications due to the poor fluid output, which can be prevented by using a retractor or a working sheath.

This study has several limitations. First, only a few case series with short follow-up periods have been published on biportal endoscopic thoracic surgery. Second, 3 articles reviewed were all retrospective study, thus the inherent weakness and limitation of all retrospective studies would be expected.

## CONCLUSION

UBE technique in thoracic spine surgery is a viable, effective, and minimally invasive treatment option that, when performed by experienced surgeons, provides favorable clinical outcomes for select patients. UBE technique has remarkable advantages, but endoscopic thoracic surgery is technically challenging and

has the potential to cause serious complications. For avoidable complications, surgeons should be familiar with prevention methods and pitfalls to minimize complications.

## NOTES

### Conflicts of Interest

The authors have nothing to disclose.

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# Transforaminal Full-Endoscopic Lumbar Discectomy for Lumbar Pyogenic Discitis: A Review

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Pyogenic discitis can cause significant back pain, neurological complications, and spinal deformities. An early and accurate diagnosis of pyogenic discitis is crucial for its effective management. Magnetic resonance imaging is the gold standard for the diagnosis of pyogenic discitis. Hematologic markers such as white blood cell count, erythrocyte sedimentation rate, and C-reactive protein level are also helpful in monitoring disease progression. Furthermore, blood culture is essential for identifying the causative bacteria and selecting the antibiotic to be used. Biopsies are useful for identifying the causative bacteria when blood cultures are negative or when antibiotics are not sufficiently effective. While open biopsy or computed tomography-guided biopsy has conventionally been used for this purpose, recently, transforaminal full-endoscopic biopsies have been used to detect the causative bacteria in pyogenic discitis. Endoscopy can be used to obtain sufficient intervertebral disc samples with direct visualization, which increases the detection rate of causative bacteria and has been reported to be effective in relieving back pain through decompression for pyogenic disc space. However, the effectiveness of endoscopic surgery might be limited in cases of advanced infection or extensive bone destruction. In such situations, open surgery with anterior reconstruction using minimally invasive techniques may be preferred. Although it has its limits, transforaminal full-endoscopic discectomy has emerged as a standard method for identifying the causative bacteria in pyogenic discitis. It also has a high therapeutic effect.

**Key Words:** Spondylodiscitis, Discectomy, Percutaneous, Endoscopy, Biopsy, Debridement

## INTRODUCTION

The diagnosis and treatment of pyogenic discitis involve symptom assessment, magnetic resonance imaging (MRI), hematological tests, and bacteriological examinations [1-5]. The principle of treatment for pyogenic discitis is appropriate antibiotic treatment. Failure of antibiotic treatment may cause difficult-to-treat conditions, including persistent back pain, ver-

tebral compression, kyphotic deformity, formation of epidural abscesses, and spinal instability, which necessitate surgical intervention [6,7]. Prompt diagnosis and early intervention with the appropriate antibiotics help resolve pyogenic discitis without the need for surgical intervention. Effective treatment for bacterial discitis involves a sequential process: first, discitis is diagnosed based on symptoms, MRI, and hematological tests. The subsequent empiric antibiotic therapy is then commenced,

preferably immediately after diagnosis, followed by tailoring the antibiotic therapy to ensure that it is effective against the causative bacteria identified. While blood cultures are useful for identifying the causative pathogen, the detection rate using this method is approximately 50%. Reportedly, biopsies help effectively identify the causative bacteria, with a higher detection rate of 70%–100%. Recently, an increasing number of reports on biopsy methods have been published, with computed tomography (CT)-guided percutaneous biopsy becoming the preferred option as it is less invasive and safer than open biopsy [5]. The body of evidence on the effectiveness of full-endoscopic biopsies in discitis is also growing [8,9]. In full-endoscopic biopsy, a sufficient amount of samples are obtained from the intervertebral discs, leading to a higher detection rate of the causative microorganisms. Endoscopic decompression and lavage of the intervertebral space contribute to ameliorating postoperative back pain and facilitate antibiotic treatment success, ultimately reducing the need for surgical intervention.

With the widespread use of full-endoscopic lumbar surgery, the number of reports on its effectiveness as a minimally invasive initial treatment for intervertebral discitis is increasing, creating a need to summarize the existing literature on the topic [10,11]. This review aims to provide a comprehensive overview of transforaminal full-endoscopic lumbar discectomy (FELD) for pyogenic discitis.

## DIAGNOSIS OF PYOGENIC DISCITIS

### 1. Symptoms

Sapico and Montgomerie found that 50% of patients with pyogenic discitis experienced symptoms persisting for over 3 months before diagnosis [1]. Pain is the dominant symptom and presents in 90% of the patients, whereas fever is observed in only 52%, with chills or fever spikes being rare [12]. The pain is primarily localized to the spine but may radiate to other areas, such as the abdomen, hip, leg, scrotum, groin, or perineum. Radicular symptoms were found in 50%–93% of cases [13].

The primary signs of spondylodiscitis include tender paravertebral muscles, muscle spasms, and limited spinal movement. Neurological complications, such as spinal cord or nerve root compression and meningitis, occur in approximately 12% of patients [14].

Progression of spinal pain to radicular symptoms, weakness, and paralysis may indicate the formation of an epidural abscess or kyphotic collapse at the infection level. Sensory involvement is rare, whereas motor and long-tract signs are more common

because of anterior cord compression [15,16].

### 2. Radiology

As MRI is more sensitive than bone scans, it has become the gold standard for evaluating pyogenic spondylodiscitis. It shows characteristic findings early in the disease course, with a sensitivity of 96%, specificity of 92%, and accuracy of 94% in diagnosing spondylodiscitis [2]. The postinflammatory phase of the disease is marked by characteristic histological changes, including vascularized fibrous tissue, fatty bone marrow transformation, subchondral fibrosis, and osteosclerosis, which can be clearly visualized using MRI. In addition, MRI can be used to monitor therapeutic responses during treatment [17].

In patients with symptoms for less than 2 weeks, MRI findings help diagnose or are suggestive of pyogenic spondylodiscitis in 55% and 36% of the cases, respectively [18]. After 2 weeks, the rates of correct and possible diagnoses are 76% and 20%, respectively. Early MRI abnormalities occur because of edema and inflammatory cells infiltrating the vertebral body and disc spaces. This causes the marrow to have lower intensity on T1-weighted images and higher intensity on T2-weighted sequences. The intervertebral disc is also visualized as high-intensity on T2-weighted images owing to increased water content. Gadolinium-based contrast agents may show enhancement at the endplate–disc interface early in the infection stage; the enhancement area widens as the disease progresses. Follow-up MRI findings of pyogenic spondylodiscitis may show variable tissue responses. It has been reported that changes in C-reactive protein (CRP) are correlated with changes in soft tissue, and changes in erythrocyte sedimentation rate (ESR) are correlated with changes in bone on MRI. Similar to the ESR, which normalizes more slowly than CRP, bone abnormalities on MRI take more time to be normalized than soft tissue abnormalities. If ESR or CRP increases over the course of treatment for discitis, a follow-up MRI may be required to determine whether this is due to treatment failure or inflammation elsewhere [19].

### 3. Hematology

In patients with spondylodiscitis, the white blood cell count is usually normal; however, it may be elevated in 35% of cases, typically not exceeding 12,000 cells/mm<sup>3</sup>. The ESR is often elevated, with a mean value of 85 mm/hr (normal value, 0–20 mm/hr), and tends to decline with appropriate medical treatment. The CRP rises within 6 hours of bacterial infection and



is elevated in more than 90% of patients with discitis. Although CRP and ESR are elevated after infections, CRP normalizes after appropriate treatment of an infectious process faster than ESR. CRP level is another clinically useful marker for monitoring disease progression [3,4].

#### 4. Bacteriology

Blood, urine, and focal suppurative processes should be cultured to identify the causative organism of discitis. Blood cultures are positive in approximately 50% of cases and can aid in guiding antimicrobial therapy. If the organism cannot be identified using minimally invasive methods, direct culture from the affected vertebral body and/or disc space should be attempted. CT-guided percutaneous needle biopsy is a safe and precise diagnostic option, with accuracy rates ranging from 70%–100%. Open biopsies have a diagnostic accuracy of over 80% but are associated with higher morbidity [5].

Nonculture amplification-based DNA analysis is highly sensitive and specific, particularly in cases where standard culture methods fail to identify the infectious agent. This method can be useful in identifying the cause of infectious spondylodiscitis and guiding species-specific treatment when blood and disc aspirate cultures are negative [20].

In cases where fungal or mycobacterial infections are suspected based on subacute presentation, along with negative Gram staining and bacterial culture, cultures specific for fungi and mycobacteria should be obtained. Whenever possible, antibiotics should be withheld until cultures are obtained to ensure accurate identification of the causative organism and appropriate treatment.

## BIOPSY METHODS

Empirical antibiotic therapy before biopsy can lead to challenges in isolating organisms from bacteriological cultures because the microbial growth rate significantly decreases when patients are already on antibiotics (from 40% to 25%). However, despite this difficulty, spinal biopsy results in a direct change in management for 35% of patients with discitis, and it remains valuable even if the patient has already started antibiotic treatment. Spinal biopsy should be performed before initiating antibiotics, with samples sent to both the pathology and bacteriology departments for accurate diagnosis and appropriate management [21].

Biopsy is primarily indicated in patients with suspected spondylodiscitis and negative blood cultures. Percutaneous

biopsy is a safe procedure that can be performed using guided CT-scanning or endoscopy [22]. Endoscopy facilitates both the biopsy procedure and discectomy and drainage, leading to better bacterial recovery compared with that after CT-guided spinal biopsy. Endoscopy is currently considered the standard method for obtaining samples, as it enables further surgical treatment if necessary [8]. If the initial biopsy result is negative, a second biopsy should be performed; in any case, more than 6 samples from different areas of the surgical field should be collected to improve diagnostic accuracy [9].

Currently, surgical biopsy is more commonly used than minimally invasive techniques [23,24]. However, with advancements in endoscopy, open surgery is becoming less favored as a biopsy method. Biopsy after antibiotic treatment may result in a negative culture [22,25]; therefore, antibiotic suppression before biopsy is recommended. However, this approach is controversial, as negative culture results may be yielded in approximately 40% of spondylodiscitis cases without prior antibiotic treatment [26,27].

#### 1. Usefulness of Endoscopic Discectomy

One study reported on 15 consecutive patients with pyogenic spondylodiscitis of the thoracic or lumbar spine [10]. All patients had previously failed preoperative antibiotic treatment. Transforaminal full-endoscopic debridement and irrigation were performed under local and intravenous anesthesia. All patients experienced immediate postoperative pain reduction. After an average of 3.7 weeks of antibiotic administration, inflammation in patients was ameliorated, and a high spinal fusion rate was achieved. The authors also reported that they were able to reduce epidural abscesses based on imaging, improve clinical symptoms caused by the abscess, and eliminate the psoas abscess [10].

Another study retrospectively reviewed the medical records of 21 patients who had undergone FELD for advanced lumbar infectious spondylitis [11]. Causative bacteria were identified in 90.5% of the biopsy specimens, and appropriate antibiotics were prescribed based on the predominant pathogen. The overall infection control rate was 86%. Most patients reported satisfactory recovery and relief from back pain, except for those with multilevel infections who required additional anterior debridement and fusion. FELD successfully provided a bacteriological diagnosis, relieved symptoms, and contributed to the eradication of lumbar infectious spondylitis. The indications for FELD can be extended to patients with spinal infections, paraspinal abscesses, or postoperative recurrent infections.

However, patients with multilevel infections may experience limited benefits from FELD because of poor infection control and mechanical instability of the affected segments [11].

## OPERATIVE PROCEDURE

In the aforementioned study, FELD was performed in patients with infectious spondylitis of the lumbar region. Patients were placed in the prone position on a radiolucent frame suitable for fluoroscopy, and all procedures were performed under local anesthesia with conscious sedation, similar to the standard lumbar discography procedure.

Under fluoroscopic guidance, the target site within the infected disc was located, and the entry site on the skin was marked 8–12 cm from the midline. After sterile preparation, draping, and local anesthesia administration, a spinal needle was inserted directly into the center of the targeted disc. A guidewire was then introduced through the needle into the central disc space, and the needle was removed. A small incision (approximately 1 cm) was made, and a dilator and cannulated sleeve were sequentially guided over the wire and into the center of the disc. Fluoroscopy was repeated in 2 orthogonal planes to ensure the correct positioning of the endoscope tip [11].

The tissue dilator was removed, and a cutting tool, a cylindrical sleeve with a serrated edge at its distal end, was inserted to harvest a core biopsy specimen of the infected tissue. Discectomy forceps were then inserted through the cannulated sleeve to extract additional infected tissue from the disc. Percutaneous debridement was performed in a piecemeal manner by manipulating the biopsy forceps, flexible rongeurs, and shaver into different positions to remove as much infected tissue as possible. Fluoroscopy was used for monitoring. The same procedure was repeated on the opposite sides of the disc. Working sheaths were retained on both sides to allow sufficient extirpation and extensive debridement of the infected intervertebral disc, and even parts of the endplate were removed from different endoscopic directions.

Approximately 35 mL of povidone-iodine was diluted with 1,000 mL of normal saline to obtain a 3.5% betadine solution, which was used for irrigation after biopsy and debridement. At least 10,000 mL of the diluted betadine solution was used for irrigation [11].

### 1. Limitations of Full-Endoscopic Discectomy and Lavage

The effectiveness of transforaminal full-endoscopic surgery

for pyogenic spondylodiscitis has been demonstrated in previous studies [10,28,29]; however, most of these studies focused on early-stage infections. In one study wherein the posterolateral endoscopic technique was used in 4 patients with pyogenic spondylodiscitis, all patients experienced immediate back pain reduction after surgery and were subsequently treated with parenteral antibiotics, but not all had successful outcomes. Two possible causes for these adverse effects have been identified. First, all patients were compromised hosts with comorbidities, such as diabetes. Second, vertebral destruction had progressed in the patients after they underwent conservative therapy for some time before surgery. Aggressive debridement with the endoscopic procedure may have increased instability and exacerbated pain in certain cases, leading to neurological disorders, such as foraminal stenosis. Severe cases require open surgery with anterior reconstruction using an iliac strut bone graft and posterior instrumentation [30].

The progression of vertebral destruction, along with preoperative destructive changes at the vertebral level, can lead to local kyphosis progression during follow-up after aggressive debridement with full-endoscopic surgery [10,11]. To ensure successful outcomes, it is essential to quantify and evaluate the degree of preoperative bone destruction and to determine clear indications for endoscopic surgery. In cases of extensive bone destruction, open debridement and bone grafting can provide better stability and symptom relief and prevent kyphosis. Recently, a minimally invasive direct lateral retroperitoneal approach that offers thorough debridement and spinal reconstruction has been reported as an alternative surgical treatment for lumbar discitis and osteomyelitis [31,32]. Therefore, in cases of significant vertebral destruction, it is advisable to consider open surgery using minimally invasive techniques as the primary treatment rather than endoscopic procedures.

## CONCLUSION

In the treatment of pyogenic discitis, transforaminal full-endoscopic discectomy increases the identification rate of causative bacteria by facilitating direct visualization and helping obtain a sufficient amount of disc sample, enabling the selection of appropriate antibiotics. It is less invasive and safer than open biopsy or CT-guided biopsy. In addition, as a large amount of intervertebral discs can be removed, transforaminal full-endoscopic discectomy decreases intervertebral compression and is also highly effective in relieving back pain caused by discitis. Furthermore, lavage can be performed at the same time as the biopsy, aiding in diagnosis with a high therapeutic effect.

Thus, although it has its limitations, transforaminal full endoscopy can be considered the procedure of choice for the diagnosis and treatment of discitis in the future.

## NOTES

### Conflicts of Interest

The authors have nothing to disclose.

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# A Review of Fully Endoscopic Lumbar Interbody Fusion

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Over the past 10 years, fully endoscopic lumbar interbody fusion (FE-LIF) has been widely reported as a rational alternative to minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF), and several FE approaches for interbody fusion have been published. The short-term surgical outcomes of FE-LIF are reportedly superior to those of MIS-TLIF and conventional posterior LIF in terms of intraoperative blood loss and short-term back pain. However, the complication rate, medium-term clinical outcomes, and fusion rate have not been reported to be different in all uncontrolled studies. The challenges associated with FE-LIF include a longer operative time, which means a steep learning curve, and limited surgical indications, which leads to patient selection bias. FE-LIF is an excellent surgical option for treating degenerative disc disease, spinal instability, and spondylolisthesis. Although the amount of evidence is very small in existing studies and the long-term follow-up data are limited, this technique shows favorable clinical outcomes in selected patients.

**Key Words:** Full-endoscopic lumbar interbody fusion (FE-LIF), Full-endoscopic trans-Kambin's triangle lumbar interbody fusion (FE-KLIF), Full-endoscopic posterior lumbar interbody fusion (FE-PLIF), Treatment outcomes, Intraoperative complications

## INTRODUCTION

Various surgical procedures for lumbar interbody fusion (LIF) have been reported, including posterior LIF (PLIF), transforaminal LIF (TLIF), lateral LIF (LLIF), and anterior LIF (ALIF). LIF is indicated for various lumbar degenerative diseases, such as lumbar canal stenosis, spinal instability, spondylolisthesis, foraminal stenosis, disc herniation, and degenerative scoliosis [1]. Conventional open posterior fixation surgery is preferred as it has a shallow learning curve, offers sufficient decompression, and has wide indications and steady operative outcomes. However, due to the large incision and extensive paravertebral muscle dissection, the innervation and blood supply of the paravertebral muscles, such as multifidus and longissimus

muscle, are considerably damaged during conventional posterior fixation surgeries. Many patients (~25%–35%) intractable low back pain (LBP) after conventional PLIF and TLIF accounts for an increase in back pain visual analogue scale (VAS) scores from 3 to 5, which adversely affects patients' quality of life [2]. Therefore, many spine surgeons have made significant efforts to reduce surgical complications such as soft tissue damage and LBP caused by conventional PLIF and TLIF, respectively. In 1988, Wiltse and Spencer [3] described a posterolateral approach through the space between the multifidus and the longissimus muscle to the foramina for the treatment of far-lateral disc herniation, spinal canal stenosis, and lumbar spondylolisthesis. Because the Wiltse approach significantly reduces paraspinal muscle damage and blood loss and makes direct ex-

posure to the insertion point of the pedicle screw easier, it has been widely used for pedicle screw insertion. In 2002, Foley et al. [4] reported minimally invasive transforaminal fusion. Since its introduction, the MIS-TLIF procedure has gained consensus among most spine surgeons. The terms Wiltse TLIF and MIS-TLIF are often used interchangeably these days. Wiltse TLIF and MIS-TLIF are both minimally invasive surgical procedures with the advantages of less intraoperative bleeding, paravertebral muscle damage, shorter hospital stay, and significantly reduced long-term complications such as those with intractable LBP [5-7]. Many studies have reported the clinical benefits of Wiltse TLIF and MIS-TLIF in the treatment of degenerative lumbar diseases, with less intraoperative blood loss (50–80 mL) and shorter hospital stays (2–5 days) [8,9]. Over the past few decades, the surgical technique has become more advanced and less invasive [10]. Spinal endoscopic technology and techniques have been continuously evolving since the early 2000s, with various innovations being introduced over the years [11-18]. The use of a uni-portal endoscopic system is becoming more popular for decompressing central canal and lateral recess stenosis [19-24]. Full-endoscopic LIF (FE-LIF) has been made possible through advancements in endoscopy technology, improved endoscopic instruments to facilitate soft and bony tissue removal, and improved surgical skills in endoscopic discectomy and neural decompression [25]. In full-endoscopic transforaminal lumbar discectomy, the target working zone is Kambin triangle. The area is also crucial for transforaminal fusion techniques, as it determines the entry point into the intervertebral disc. Disc height determines the cranial and caudal dimensions of the neuroforamen. The length of the pedicle, facet joint arthritis, and hypertrophic ligamentum flavum influence the size of Kambin triangle. Furthermore, pathological conditions such as lumbar disc herniation, degenerative spondylolisthesis, and foraminal stenosis can lead to changes in the position of the nerve roots. In the case of herniated discs, the exiting nerve root can deviate in any direction, depending on the location of protruding or extruding disc material. Kim et al. [25,26] reported the use of uniform portal facet-sacrificing post-erolateral TLIF (ETLIF). ETLIF was described as a means for performing interbody fusion using a large-channel endoscope with unilateral facet removal to create a working space for disc preparation and insertion of the interbody cage. Conversely, Morimoto and Ishiyama et al. [27,28] reported on the full-endoscopic trans-Kambin triangle LIF (FE-KLIF). They partially removed the superior articular process using a surgical drill until Kambin's triangle was large enough to safely insert a box-type dilator in the next step.

Osteotomy aims to remove an adequate amount of bone required to expose 12 mm of the intervertebral disc surfaces. Kim et al. [34] reported that on radiological evaluation, both ETLIF and FE-KLIF showed promising results in terms of fusion rate and cage subsidence, comparable to those of other fusion methods. Exiting nerve root injury and subsidence are the most critical complications of FE-KLIF [29,30]. In contrast, incidental durotomy and traversing nerve root injury are possible complications related to ETLIF [31,32]. To prevent nerve root injury, Morgenstern et al. [33] suggested approaching Kambin triangle by performing foraminoplasty and disc preparation, followed by the insertion of the expandable cage and pedicle screws. Kim et al. [34] reported that the application of single-level ETLIF helped achieve better clinical outcomes and fusion rate with less subsidence than microscopic MIS-TLIF in midterm evaluation among patient cohorts. However, in some cases, other LIF procedures were preferable to ETLIF or FE-KLIF. First, the pelvis is often an obstacle for patients with degenerative spondylolisthesis at the L5/S1 level. Therefore, it may be difficult to insert the cage correctly. Second, in terms of operations, time, and corrective force, lateral LIF may be preferable to FE-KLIF for the correction of multilevel vertebral deformities is required. Finally, conventional PLIF or TLIF is preferable in cases requiring posterior decompression. Examples include cases with severe bony canal stenosis, ossification of ligamentum flavum and those with significant thickening of the ligamentum flavum, which makes it challenging to achieve symptomatic improvement with indirect decompression [27]. The full- endoscopic interlaminar approach, which is a well-known standard in full-endoscopic spine surgery, has rarely been applied to endoscopic lumbar fusion surgery. Full-endoscopic posterior lumbar interbody fusion (FE-PLIF) via an interlaminar approach can help achieve direct decompression of bony canal stenosis and safe interbody fusion.

To the best of our knowledge, only a few systematic reviews and meta-analyses have been conducted on FE-PLIF have been published. This review aims to clarify the distinction between FE-KLIF and FE-PLIF, and reports that FE-LIF is an extremely minimally invasive and safe surgical procedure for degenerative lumbar disease.

## MATERIALS AND METHODS

Although this study was a narrative review, we also followed the Cochrane Handbook for Systematic Reviews of Interventions protocol. This study was performed according to Preferred Reporting Items for Systematic Reviews and Meta-Anal-

yses as closely as possible [35,36].

## 1. Search Strategy

We searched Medline using PubMed, Embase, and the Cochrane Library databases on July 10, 2023, without restrictions on revision, publication type, or language. The following search terms were used : “(full endoscopic OR percutaneous endoscopic) AND (minimally invasive) AND (interbody fusion) AND (lumbar) AND (transforaminal) OR Kambin OR posterior )”

## 2. Eligibility Criteria

In this study, only English-language articles were included. First, the remaining articles were assessed by title and abstract, and duplicate articles were erased. We excluded articles on air-based microendoscopic techniques using tubular retractor systems (MED system), laparoscopic ALIF, and endoscopy-assisted LLIF or oblique LIF. Systematic reviews, meta-analyses, cadaver studies, case reports, technical reviews, and reports that did not analyze the cases were excluded. After the screening, the full texts were reviewed and excluded if they fell under any of the following exclusion criteria: (1) the noncomparative study; (2) articles about standalone endoscopic fusion without transpedicle screw fixation; and (3) not related to clinical outcomes, including pain, complications, surgical time, blood loss, and fusion rate. The extracted details included first author, study design, year, and demographics information. It also covered the indication for surgery, surgical procedure (including anesthesia and intervertebral cage), operative time, blood loss, clinical scores (VAS for back and leg pain, and Oswestry Disability Index [ODI]), outcomes related to complications, and fusion rate.

# RESULTS

## 1. Study Selection

The database search resulted in the identification of 115 studies. After screening the titles and abstracts according to the inclusion/exclusion criteria and removing the duplicates, 15 studies remained for full-text review. Finally, 15 articles were included in this study [37-49].

## 2. Characteristics of Eligible Studies

Among all studies, indications were identified as lumbar de-

generative diseases such as disc herniation, canal stenosis, and spondylolisthesis. All studies reported clinical outcomes, including preoperative and postoperative VAS scores of the back/leg or ODI, surgical outcomes, including operation time, blood loss or incidence of complications, and fusion rates (Table 1).

## 3. Clinical Results of the Selected Studies

The clinical outcomes are summarized in Table 1, with surgical invasiveness assessed for blood loss and operative time. The VAS and ODI scores used to measure low back and leg pain were reported in 15 studies, all of which reported improved scores after surgery. There was no significant difference in the improvement rate of the VAS of the back/leg and ODI differences between FE-KLIF, FE-PLIF, MIS-TLIF, and conventional PLIF. Intraoperative blood loss was higher in MIS-TLIF and conventional PLIF than in FE-KLIF and FE-PLIF. The operative time was significantly longer in the FE-KLIF and FE-PLIF groups. The overall fusion rates at the final follow-up were not significantly different between FE-KLIF, FE-PLIF, MIS-TLIF, and conventional PLIF.

## 4. Complications

Complications are summarized in Table 1. Ishihama et al. [28] reported that one patient who underwent FE-KLIF complained of an existing nerve root injury that improved within 2 weeks after surgery. Postoperative dysesthesia was the most frequent complication and was primarily caused by exiting nerve root injury via the trans-Kambin triangle or the transforaminal approach. In this series, postoperative dysesthesia of the exiting nerve root was confirmed in 17 of the 532 FE-KLIF cases (3.2%). Unlike the trans-Kambin triangle or transforaminal approach, in the case of FE-PLIF, postoperative dysesthesia or motor weakness is mainly caused by traversing nerve root injury at the lateral recess. Morgenstern et al. [30] reported that 12 of their cases (23.5%) developed transitory 190 ipsilateral dysesthesia. In all 191 cases, dysesthesia resolved completely by an average of 7.2 weeks postoperatively after oral pregabalin treatment or selective nerve block. Transitory ipsilateral muscle weakness developed in 2 of the 12 patients, and resolved fully by an average of 8.2 weeks after surgery. In this series, postoperative dysesthesia of the traversing nerve root was confirmed in 3 of 82 (3.7%) FE-PLIF cases. Furthermore, 1 of the 131 MIS-TLIF and 40 conventional PLIF cases had postoperative dysesthesia. Ao et al. [44], who compared KLIF and MIS-TLIF, reported that one patient in the KLIF group showed a decrease in muscle

**Table 1.** Clinical results, blood loss, operative time, complications of the selected studies

Study	VAS improvement (%)	ODI improvement (%)	Blood loss (mL)	Operative time (min)	Complication rate	Fusion rate (%)	Surgical technique
Osman [37] 2012	VAS back 55 VAS leg 53	None	57.6	174	16.6% 10 Cases of residual symptom 2 Cases required repositioning of misplaced pedicle screws	None	60 Patients; full-endoscopic transforaminal lumbar interbody fusion without foraminoplasty
Wang and Grossman [38] 2016	None	68.4	65	113.5	0%	100	10 Patients; endoscopic transforaminal lumbar interbody fusion without foraminoplasty
Morgenstern et al. [30] 2020	VAS back 48 VAS leg 43	18.5	103.6	None	29.4% 12 Cases of temporal nerve disorder 3 Cases of cage subsidence	None	51 Patients; full percutaneous transforaminal lumbar interbody fusion using the facet-sparing
Kolcun et al. [39] 2019	None	28.7	65.4 (1 level) 74.7 (2 levels)	84.5 (1 level) 128.1 (2 levels)	3% 1 Case of infection 2 Cases of cage migration	100	100 Patients; endoscopic minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF)
Jin et al. [40] 2020	VAS back 51 VAS leg 69	30.7	25.0	213	7.7% 1 Case of cage subsidence 2 Cases required reoperation	100	39 Patients; percutaneous endoscopic lumbar interbody fusion
Gong et al. [41] 2021	VAS back 37 VAS leg 56	41.1	53	137	6.3% 2 Cases of dural tear 2 Cases of temporal nerve disorder 1 Case of cage migration	100	96 Patients; full-endoscopic transforaminal lumbar interbody fusion
Li et al. [42] 2021	VAS back 47 VAS leg 53	41.5	None	131.5	0%	100	20 Patients; full-endoscopic oblique lateral lumbar interbody fusion
Ishihama et al. [28] 2022	VAS back 60 VAS leg 51	None	50	170	10% 1 Case of temporal nerve disorder	None	10 Patients; full-endoscopic trans-Kambin triangle lumbar interbody fusion
Wang et al. [43] 2022	None	24.5	30	149	0%	93.8	16 Patients; full-endoscopic lumbar interbody fusion (FE-KLIF)
Ao et al. [44] 2020	FE-KLIF VAS back 39 VAS leg 53 MIS-TLIF VAS back 42 VAS leg 49 FE-KLIF VAS back 66 VAS leg 61	43.0	378	143.0	2.9% 1 Case of temporal nerve disorder	85.3	56 Patients; FE-KLIF
		43.3	460	103.6	2.5% 1 Case of dural tear	92.3	58 Patients; MIS-TLIF
Yin et al. [45] 2021		43.0	378.1	204.1	8.9% 1 Case of temporal nerve disorder	87.5	35 Patients; FE-KLIF
	Open-PLIF VAS back 63 VAS leg 64	43.3	460.7	99.8	4 Cases of residual symptom 10.5% 2 Cases of dural tear 2 Cases of infection 2 Cases of residual symptom	94.8	40 Patients; conventional posterior lumbar interbody fusion (PLIF)

(Continued to the next page)



Table 1. Continued

Study	VAS improvement (%)	ODI improvement (%)	Blood loss (mL)	Operative time (min)	Complication rate	Fusion rate (%)	Surgical technique
Han et al. [46] 2022	FE-KLIF	28.8	48.9	146.2	3.6% 2 Cases required reoperation	89.7	39 Patients; FE-KLIF
	VAS back 65						
	VAS leg 66						
	MIS-TLIF	28.3	86.6	127.9	3.4% 2 Cases required reoperation	95.4	43 Patients; MIS-TLIF
	VAS back 66						
Li et al. [47] 2020	VAS leg 69						
	FE-PLIF	30.7	49.5	187.7	18.2% 4 Cases of cage subsidence	72.7	22 Patients; full-endoscopic posterior lumbar interbody fusion (FE-PLIF)
	VAS back 43						
	VAS leg 42						
	MIS-TLIF	33.7	267.7	121.6	0%	70.0	30 Patients; MIS-TLIF
Jiang et al. [48] 2021	VAS back 45						
	VAS leg 47						
	VAS back 83.5	69.7	43.3	209.2	13.6% 2 Cases of transient traversing nerve dysesthesia	100	24 Patients; FE-PLIF
	VAS leg 89.1				1 Case of infection		
					8.3%		
Tan et al. [49] 2022	VAS back	None	None	(A) 410.00	1 Case of infection	77.7	36 Patients; divided into three groups of 12 each; FE-PLIF
	(A) 85.4, (B) 85.8, (C) 88.3			(B) 364.42	1 Case of dural tear (A)		
	VAS leg			(C) 319.17	1 Case of incomplete reduction (A)		
	(A) 91.0, (B) 92.6, (C) 91.9						
					1 Case of dysesthesia (traversing nerve) (B)		

VAS, visual analog scale; ODI, Oswestry Disability Index.

(A) Group A: the initial, (B) Group B: the subsequent, (C) Group C: the last 12 cases.

strength to MMT 4/5 in the quadriceps femoris, which recovered by one month after surgery. A dural tear occurred in one patient in the MIS-TLIF group. Yin et al. [45] reported no significant difference in the complication rates between the FE-KLIF and conventional PLIF groups ( $p=0.67$ ). Two patients who underwent conventional PLIF developed a surgical site infection, and 2 developed cerebrospinal fluid leakage. Conservative treatment was successful in all cases. Two patients complained of postoperative residual numbness, which resolved over time. In their series, there were no significant differences in the fusion rates between FE-KLIF, FE-PLIF, and MIS-TLIF.

## DISCUSSION

The Endo-LIF procedure was first reported by Leu and Hauser [50] in 1996. Many studies have reported that FE-KLIF and other types of full-endoscopic lumbar decompression and interbody fusion lead to faster recovery and ambulation, along with less collateral tissue damage during microsurgery and tubular surgery, resulting in an early return to normal life for patients [18,37,38,44,51-53]. Few other study results were consistent with these reports, showing less blood loss, shorter hospitalization, and earlier LBP improvement in the FE-PLIF group [47-49]. There was no significant difference in clinical and radiologic outcomes at the final follow-up between FE-KLIF, FE-PLIF, and MIS-TLIF. Nevertheless, FE-PLIF requires more time for spinal decompression and endplate preparation than conventional fusion techniques such as MIS-TLIF.

Postoperative dysesthesia caused by nerve damage is a common complication of FE-KLIF. Ahn [18] reported that the working tube used in surgical procedures could potentially irritate the exiting nerve root, especially in cases with long surgery times. Conscious sedation and neuromonitoring may help reduce the incidence of intraoperative root injury. Preoperative magnetic resonance imaging is helpful in detecting anatomical anomalies such as conjoined nerve roots [54]. The surgeon's knowledge of anatomical landmarks and precise C-arm fluoroscopic guidance may help prevent neurological injury.

Choi et al. [55] reported that the overall complication rate of FE-KLIF was 13.2% (range, 0%-38.6%). The most frequent complication observed was postoperative dysesthesia, which is primarily caused by exiting nerve root injury during the trans-Kambin triangle or transforaminal approach [56]. In patients with a narrow Kambin triangle, there is a risk of irritation to the exiting nerve root if the cannula is placed too close to the exiting nerve root. Unlike the trans-Kambin triangle or transfo-

raminal approach, the FE-PLIF procedure uses an interlaminar space to reach the target pathological structure under a familiar surgical anatomy. In FE-PLIF, postoperative dysesthesia or motor weakness is mainly caused by traversing nerve root injury at the lateral recess. Compared with the advantages of other approaches, patients with severe bilateral and central bony canal stenoses may benefit more from this interlaminar approach, which enables better access to the contralateral side than the unilateral Kambin triangle.

Li et al. [47] reported that fusion rates with definite grades were not significantly different between the FE-PLIF and MIS-TLIF groups, reaching 73.3% in the FE-PLIF group, similar to those reported in previous studies [17,37,56,57]. Recent research has highlighted the suitability of expandable interbody fusion cage implants for full-endoscopic fusion [58]. These cages, requiring smaller cannulas, offer several advantages such as adjustable height and lordosis angle, facilitating controlled restoration of disc height and segmental lordosis. In addition, the expansion force of the cage may result in greater indirect decompression, thereby reducing the risk of cage migration.

Nonetheless, long-term follow-ups should be conducted to further evaluate the efficacy of interbody fusion and the adverse effects of cage subsidence in FE-KLIF and FE-PLIF procedures.

The indications of FE-KLIF and ETLIF are generally similar to those of conventional open PLIF or TLIF. In this review, FE-KLIF was performed for a wide range of diseases, including canal stenosis, degenerative spondylolisthesis, lumbar disc herniation, and lumbar degenerative disc disease. However, in some cases, other intervertebral fusion techniques are preferred over KLIF or ETLIF. First, in patients with degenerative spondylolisthesis at L5/S1, the pelvis is often an obstacle, and it may be difficult to insert the cage correctly. Second, given the operation time and corrective force required, lateral LIF may be preferable to FE-KLIF and ETLIF when multilevel vertebral deformities are corrected. Finally, conventional PLIF or TLIF is preferable in cases requiring posterior decompression. Examples include cases with ossification of the ligamentum flavum and those with significant thickening of the ligamentum flavum, which makes it challenging to achieve symptomatic improvement with indirect decompression [59]. The posterior interlaminar approach, a well-known standard in full-endoscopic spinal surgery, has rarely been used in endoscopic lumbar fusion surgery. FE-PLIF via an interlaminar approach can help achieve direct decompression of bony canal stenosis and safe interbody fusion.

## CONCLUSION

According to this narrative review, the overall outcomes, including short-term outcomes, surgical complications, and fusion rates, were not significantly different among FE-KLIF, FE-PLIF, MIS-TLIF, and conventional PLIF. However, in terms of rapid recovery after surgery with less invasiveness, less bleeding, and diminished surgery-related back pain, FE-KLIF and FE-PLIF are more favorable than MIS-TLIF and conventional PLIF, despite the disadvantages of a steep learning curve and longer operation time.

## NOTES

### Conflicts of Interest

The authors have nothing to disclose.

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# Essential Surgical Techniques During Unilateral Biportal Endoscopic Spine Surgery

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Unilateral biportal endoscopic spine surgery (UBE) is a popular minimally invasive method for various types of spinal disease. UBE is similar to full percutaneous endoscopic spinal surgery in that it uses endoscopic instruments and similar to microscopic spinal surgery in that it uses a floating technique. UBE is a useful surgical technique in unilateral or bilateral decompression for the treatment of spinal canal stenosis, foraminal stenosis, ossification of the ligament flavum, low-grade spondylolisthesis, and adjacent segment degeneration. This surgical technique has several advantages over conventional spine surgery, including less tissue damage, less blood loss, shorter hospital stays, and faster recovery. In addition, the early clinical outcomes are favorable, despite the potential for complications, such as dura tearing, nerve traction injury, and postoperative hematoma. The essential surgical techniques in UBE are patient positioning, portal creation, endoscopic visualization, decompression, and fusion. Postoperatively, patients may experience less pain, require fewer analgesics, and return to daily activities quicker. We present an overview of the essential surgical techniques used in UBE and the avoidance of complications.

**Key Words:** Unilateral biportal endoscopic spine surgery, Spinal canal stenosis, Essential surgical techniques

## INTRODUCTION

The surgical procedures for spine disease have developed significantly over the last century. Since 1970, conventional spine surgery is performed by dissecting paraspinal muscles using microscopy and special retractors. These open and microscopic spine surgeries are considered standard surgical procedures [1,2]. However, substantial advances have been achieved in surgical procedures using minimally invasive techniques aimed at reducing surgical trauma, improving clinical outcomes, and promoting postoperative recovery.

Unilateral biportal endoscopic spine surgery (UBE) was a

pioneering technique, providing a less invasive alternative to conventional spine surgery in various spinal diseases. Forst and Hausmann were the first to use an arthroscope intradisally in the early 1980s [3]. At the beginning of the 21st century, several authors introduced various spinal decompression techniques to preserve the posterior midline structures, including endoscopic spine surgery [4-6]. UBE has progressed due to the development of the endoscope and specialized surgical instruments [7]. The development of endoscopic instruments generated a subspecialty of minimally invasive spine surgery that shifts the point of visualization away from the surgeon's eye or microscope and places it directly at the site of the spine pathol-

ogy with an endoscope [8]. This technique has been used for various minimally invasive spinal decompression procedures, such as laminotomy for lumbar discectomy, unilateral laminotomy for bilateral decompression, and unilateral foraminotomy. Excellent clinical outcomes have been achieved through these techniques [7,9-11]. Additionally, they allow the visualization of the spinal structures via 2 small incisions on one side of the spine, thus minimizing tissue injury and enhancing postoperative recovery. Due to these advantages, UBE is increasingly widely performed, approximately one hundred UBE cases are performed annually at our institution.

Early endoscopic spine surgery was used generally to treat disc herniation and was less invasive than traditional open techniques. Surgeons now have the surgical instruments and expertise to treat a wide range of spine pathologies beyond lumbar disc herniation. However, the technique requires specialized training and instruments, and there is a steep learning curve for beginners. Furthermore, there are potential risks and complications, including nerve injury, dura tear, postoperative hematoma, and infection. Surgeons need to adhere to established protocols and guidelines to ensure optimal patient outcomes. This article aims to describe in detail, with references to current literature, the essential surgical techniques used during UBE.

## INDICATIONS

In general, the indications for UBE are similar to those for conventional open and microscopic spinal surgery. When conservative treatment is ineffective or the neurologic symptoms of the patient worsen, a surgical procedure by UBE is recommended. The following describes the indications and contra-

indications for a surgical procedure by UBE: (1) spinal stenosis or foraminal stenosis; (2) hypertrophied ligamentum flavum (LF), ossification of ligamentum flavum (OLF) involving less than 50% of the spinal canal; (3) low-grade spondylolisthesis (I or II). The following are contraindications for a surgical procedure by UBE: (1) central lesion on the level of the spinal cord; (2) high-grade deformity; (3) tumor or vascular malformations; (4) severe dural ossification or severe stenosis; (5) high-grade spondylolisthesis (III or IV); (6) bilateral symptomatic foraminal-extraforaminal stenosis; (7) instability of the spinal column; (8) vertebral fractures or pathologic conditions because of the risk and technical challenge (Table 1).

## SURGICAL TECHNIQUE

### 1. Anesthesia and Patient Positioning

UBE is performed under general, epidural, or spinal anesthesia. However, in cervical surgery, it is performed under general anesthesia. General anesthesia is preferred in most cases, as it allows greater muscle relaxations, facilitates patient positioning, and reduces the risk of unintended patient movement during surgery. Careful consultation with an anesthesiologist is required before performing surgery at the spinal cord level, as intraoperative neurophysiological monitoring may be necessary.

Most UBE spine surgeries are performed in the prone position using a Wilson frame or Jackson table, although it is possible to change position depending on the surgical approach. It is important to reduce lumbar lordosis and increase the foraminal space by flexing the hip and knee joints. Also, an important key in patient positioning is to reduce abdominal pressure to

**Table 1.** Indications and contraindications for UBE

	Indication	Relative contraindication	Contraindication
Cervical	Unilateral foraminal stenosis	Spinal stenosis with disc herniation (> 3 levels)	Central lesion
	Refractory pain to conservative treatments or progressive neurologic symptoms	Fused-type OLF	Segmental instability
	Cervical stenosis, less than 50% of the spinal canal	Severe dural ossification	High-grade deformity
Thoracic	Thoracic spinal stenosis	Severe stenosis	Infection
	OLF		Tumor
	Synovial cysts		Vascular malformations
Lumbar	Herniated lumbar disc	Grade II or higher spondylolisthesis	
	Cauda equina syndrome	Postoperative lumbar restenosis	
	Lumbar stenosis (central/contralateral)	Bilateral foraminal-extraforaminal stenosis	
	Modic change in vertebral endplate (level II)	Vertebral fractures	
	Severe disc degeneration (Pfirrmann grade III)		

UBE, unilateral biportal endoscopic spine surgery; OLF, ossification of ligamentum flavum.

prevent epidural bleeding.

Even cervical surgery is performed mostly using the prone position. To reduce the pressure on the abdomen, an H-shape pillow should be used to relax it. The neck should be flexed, and the upper back should slope downward. This improves venous return, reducing bleeding during surgery. To check the C6–7 level or lower, the head should be fixed by head fixation, and the shoulder should be pulled down using a plaster. During surgery, mean arterial pressure must be maintained below 80 mmHg to reduce intraoperative bleeding.

## 2. Localization and Portal Creation

When performing UBE lumbar spine surgery, the C-arm is used to check the target level and set it parallel to the endplate. At the junction of the medial pedicle line and the points 1 cm above and below the target disc space, 2 skin incisions are made. The appropriate distance between the 2 skin incisions is 2 to 3 cm apart, and the skin incisions are approximately located in the lower margin of the proximal pedicle and the midpoint of the distal pedicle (Figure 1A). The docking point for the discectomy and decompressive laminectomy is the inferior margin of the upper lamina. Obviously, in cases of obesity, a high-level disc, or hyperlordosis, it should be appropriately modified according to the patient. Since it is also different depending on the disc space angle, the angle must be determined using a preoperative radiologic image. The endoscopic portal size should be 7 mm or larger, and the working scope should be 9–10 mm or larger, so that the endoscope and instrument can be inserted properly, and the saline flow can be maintained smoothly. The direction of the skin incision can be either horizontal or transverse. To decompress the exiting nerve root or to remove up-migrated disc herniation and foraminal disc herniation on the contralateral side, 2 portals should be placed slightly below the routine portal. However, to decompress the traversing root or to remove the down-migrated disc on the contralateral side, 2 portals should be placed slightly above the routine portal. Modification of these portals can reduce unnecessary bone work.

In a paraspinous approach, the upper and lower pedicles and the transverse process of the level are indicated using the C-arm. After adjusting the angle of the C-arm parallel to the endplate of the target level, the portal is made at the junction of the lateral margin of the transverse processes and the points 1 cm above and 1 cm below the target disc space (Figure 1B). The docking point is the isthmus. There is also a method to make skin incisions at an angle of about 30°–40° and check the preop-

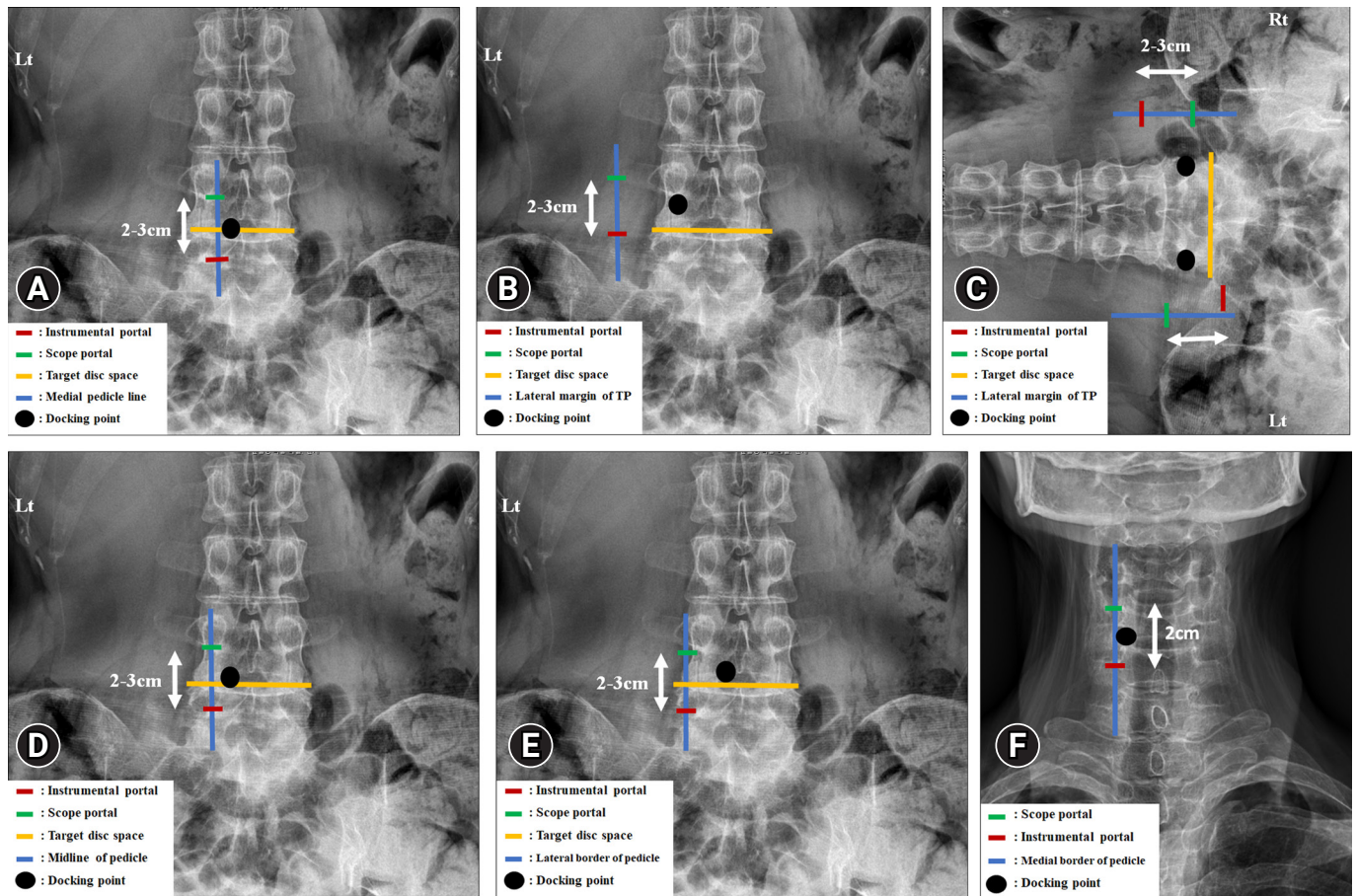
erative computed tomography or magnetic resonance imaging (MRI) in advance to determine the distance of the skin incision from the midline before performing surgery (Figure 2). After a skin incision is made, the docking point of the endoscope and the working instrument is set to the isthmus. However, at the L5/S1 level, a different location is required for the portal placement because of the iliac crest. In the L5/S1 Left side approach, the scope portal is the same as the routine portal and the working portal is 1 cm from the routine portal on the medial side. Each skin incision is made at the lateral margin of the L5 transverse process and the lateral margin of the sacral alar, and the distance between the incisions is approximately 2–3 cm. On the L5/S1 right side approach, the incision is made 1 cm from the routine portal placement on the proximal side (Figure 1C). Unlike other levels, the paraspinous approach at the L5/S1 level has a very restricted surgical field because of the prominent iliac crest, oblique pedicles, and more coronally oriented facet joint. The docking point of the endoscope and instrument is determined by the lateral border of the superior articular process (SAP), the lateral border of the sacral alar, and the osseous triangle at the base of the L5 transverse process.

In far-out syndrome decompression, the skin incision is made 1–2 cm lateral to the lateral margin of the vertebral body under C-arm fluoroscopy anteroposterior view confirmation. A skin incision is made 1 cm above and 1 cm below the intervertebral level, and the distance between the 2 skin incisions is about 2–2.5 cm. The landing point of the first dilator is very important. The aim in far-out syndrome decompression surgery is to remove the transverse process and pseudo-articulation of the sacral alar. It is important to place the first dilator through the working portal aiming at the junction of the SAP of S1 and the sacral alar and to place the endoscopic portal near the sacral alar or sacral notch for triangulation. Meticulous dissection and detachment should be performed around the bony structure, and saline flow should be maintained between the bony structure and soft tissue. The lateral aspect of the SAP, sacral alar, and even the lower border of the transverse process must be confirmed.

In revision surgery, it is important to make an incision that is slightly more lateral than when using a previous wound. Due to the characteristics of revision surgery, it is easy to lose orientation as a consequence of peridural scar tissue when entered through a previous incision; therefore, approaching from the lateral side and operating on the facet joint and lamina can be a safe procedure.

The skin incision for fusion using an endoscope is slightly different from the incision for decompression. After placing the





**Figure 1.** (A) Skin incisions for unilateral biportal endoscopic spinal surgery (UBE) in discectomy and laminectomy. Routine portal skin incisions for a left-sided approach. At the junction where the line of the medial border of pedicles and the line of the intervertebral disc space meet, 2 skin incisions are made at a point 1 cm from the top and bottom. The docking point is the inferior margin of the cranial lamina. (B) Paraspinal skin incisions for the left-sided approach. The scope portal, instrumental portal, and isthmus docking point are illustrated on the x-ray anteroposterior (AP) view. The portal is made at the junction of the lateral margin of the transverse process (TP) and the points 1 cm above and 1 cm below the target disc space. (C) Paraspinal skin incisions at the L5/S1 level for approaches from both sides. For the left-sided approach, the scope portal is the same as the routine paraspinal approach portal and the instrumental portal is 1 cm to the medial side from the routine portal. For the right-sided approach, skin incisions are made 1 cm proximal to the routine incision placement. Both docking points are the L5 isthmus. (D) UBE lumbar interbody fusion (ULIF) skin incisions for the left-sided approach. At the junction where the midline of the pedicle and the line of the intervertebral disc space meet, 2 skin incisions are made 1 cm from the top and bottom. The docking point is the inferior margin of the cranial lamina. (E) Modified far-lateral transforaminal lumbar interbody fusion using UBE skin incisions for the left-sided approach. At the junction where the lateral border of the pedicle and the line of the intervertebral disc space meet, 2 skin incisions are made 1 cm from the top and bottom. The docking point is the inferior margin of the upper lamina. (F) The skin incision points of posterior cervical foraminotomy are marked on the upper and lower pedicles around the target level. Two skin incisions for the scope portal and the instrumental portal are illustrated in the figure. The blue line indicates the medial border of the pedicle. The docking point is the "V" point between the upper and lower lamina.

C-arm parallel to the endplate, 2 skin incisions are made on the midline of the proximal and distal pedicle. Using the carinal lamina itself and the inferior margin as a docking point, a working and endoscopic portal is made approximately 3 cm away (Figure 1D). Pedicle screws are inserted using the previously made skin incisions. When performing modified far-lateral

transforaminal lumbar interbody fusion, 2 skin incisions are made at the lateral border of the pedicle (Figure 1E).

In posterior cervical surgery, a skin incision is made vertically in the midline of the pedicle under C-arm fluoroscopic confirmation. It is made near the upper pedicle and lower pedicle, about 2 cm apart (Figure 1F). The operative angle is approxi-





**Figure 2.** The appropriate trajectory for the paraspinal approach (white line) is 30° to 40°. Skin incisions should be different according to the degree of obesity or anatomical features.

mately 20°–25°. If the patient is obese, the 2 incisions should be wider and placed laterally from the midline. A #10 blade is used to make a deeper incision into the fascia until it touches the bone, with the guidance of the C-arm. Unlike lumbar, cervical surgery requires a deep enough incision because there are several layers of fascia and muscle. A wide blade is used because the dissection is safer with wider blades and can be performed without penetrating the interlaminar space.

### 3. Endoscopic Visualization

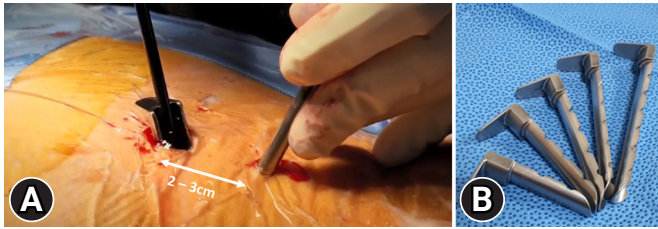
The initial docking point of the endoscope and the serial dilator is the location between the pathologic level of the spino-laminar junction and the inferior margin of the caudal lamina. Using the first serial dilator or muscle dissector, the paraspinal muscle should be sufficiently dissected on the lamina around the docking point. This is to guarantee sufficient saline patency. Muscle detachment should be performed from the lower border of the cranial lamina at the pathologic level to the upper border of the caudal lamina. It is performed by using the ablation mode of a radiofrequency (RF) probe and removing soft tissue with a muscle shaver; the endoscope and

surgical instruments are triangulated. The outer layer of LF and bulky soft tissue should be removed using a Kerrison punch or pituitary forceps to confirm the landmark of laminectomy.

It is necessary to check whether the saline patency is smooth before laminectomy. A 3,000-mL saline bag is placed 80–100 cm above the patient's back (100 cmH<sub>2</sub>O injection pressure) or an automatic pressure pump is used. Water pressure should not exceed 30 mmHg if possible [12]. The use of working sheaths or cannulas to maintain smooth water flow during surgery in patients with excessive muscle mass or who are obese is also an essential surgical technique (Figure 3). This allows the irrigation fluid to create a working space in the UBE. If a dura tear occurs, the intracranial pressure (ICP) can increase, and this increase is higher the closer it is to the cord level. Increased ICP can cause postoperative headaches, neck stiffness, seizures, and retroperitoneal fluid collection [13]. Even if there is no dura tear, high water pressure can cause postoperative back pain and neck pain, so low water pressure is recommended during UBE spine surgery (Supplementary video clip 1).

The docking point in the paraspinal approach is the lateral edge of the isthmus. Under C-arm guidance, a guide pin and instruments are placed on the isthmus and the exit of the foramen. Using a Cobb elevator, the muscles attached to the lateral edge of the isthmus, the SAP of the facet joint, and the transverse process should be dissected to create a sufficient surgical field. Radicular arteries are distributed around the facet joint; it is therefore important to prevent bleeding by adequately coagulating the area with an RF probe before performing bone work. In far-out syndrome decompression, because the radicular artery runs over the sacral notch, greater caution is necessary when dissecting muscle around the sacral notch. When bleeding is unexpectedly severe, it is necessary to control the bleeding after confirming the bleeding site by placing the endoscope close to it. Occasionally, if the hypertrophy of the facet joint is extremely severe or if access to the lateral edge of the isthmus is challenging due to a decrease in intervertebral disc height, the isthmus can be reached by approaching the lateral edge of the SAP of the lower facet joint. The next step is to check the upper and lower transverse process.

In revision surgery, anatomical landmarks are often unclear due to overgrowth by scar tissue. The caudal border of the superior lamina, medial border of the facet joint, and upper border of the caudal lamina are undercut and dissected using a diamond drill, chisel, or small-head curve curette until the healthy dura of the traversing root is exposed. When the lateral margin of the traversing root is exposed, the outer annulus of the intervertebral disc is exposed by careful medial retraction.



**Figure 3.** (A) Intraoperative field image of adequate saline flow. (B) Using working sheaths or cannulas helps to maintain a smooth saline flow during surgery.

During the process of exposure, if there is adhesion between the dura and the disc space, a blunt dissector or a small nerve hook is used carefully to dissect the scar tissue and enable safe access.

In posterior cervical surgery, the surgical field is created by dissecting neck muscle using serial dilators. Endoscope and instrument insertion require intraoperative fluoroscopic confirmation because the interlaminar space can be penetrated and cause cord injury. First, surgeons should insert a 0° endoscope and a working instrument and check the saline flow patency. Using a natural drainage or pump system, it is safe to set water pressure below 30 mmHg. Next, the V-point where the superior lamina, inferior lamina, and medial aspects of the facet joint intersect should be checked with the endoscope and instrument after triangulation. Then the surgical field can be created by removing the remnant soft tissue around the V-point. Before bone drilling, it is recommended to expose the entire lamina using an RF probe.

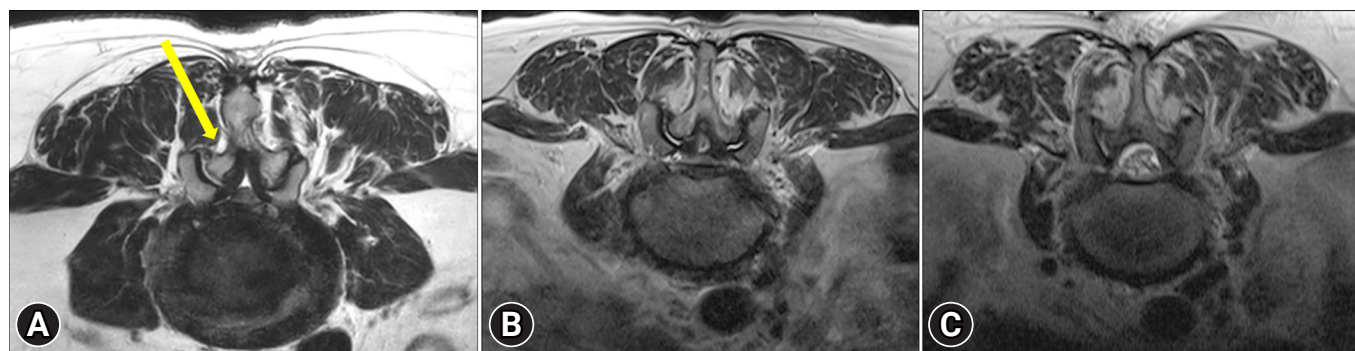
#### 4. Decompression

The anatomical landmark is checked by soft tissue dissection, and then a laminectomy is performed. The laminectomy is started from the lower border of the cranial lamina, using a drill or osteotome until a free margin of LF is obtained. Then, the V-shaped central fissure of the LF is distinguished from the lower border of the cranial lamina, bone work is performed until the cranial, lateral, and caudal sides are freely detached. To prevent fracture of the isthmus or inferior articular process, the proximal edge of the LF can be detached using curved curettes when the laminar isthmic space is narrow. The lateral margin of the nerve root and the dural sac are checked while removing the LF. Sufficient bone work and removal of the LF are done to reduce unnecessary traction. If additional bone work is required after LF, a drill can cause a dura tear; therefore, a small osteotome can be used as an alternative.

In the contralateral sublamina approach, the LF on the contralateral side and the ventral side of the lamina should be detached using a freer or curette before contralateral decompression. Contralateral sublaminoplasty should be performed until the edge of the contralateral LF is free, and is performed generally until the medial side of the contralateral facet joint is exposed. Because a dura tear can occur as a result of a central portion defect of the LF, the base of the spinous process should be removed carefully. When the contralateral lamina is undercut using an osteotome or endoscopic drill, the LF is not removed to protect the neural structure. It is recommended to proceed between the LF and the ventral side of the lamina. When a lateral recess has a calcified lesion or bony structure, a straight or curved osteotome is used for decompression rather than a Kerrison punch. However, when removing the lesion or down-migrated disc around the exiting root of the contralateral side, the laminotomy area on the ipsilateral side of the lesion can be minimal (Figure 4A), but the upper portion of the lower lamina needs sufficient bone work for easy access. It is helpful to remove the upper portion of the contralateral lamina and the SAP. By removing the contralateral LF, the contralateral traversing nerve root can be identified, and by removing the foraminal ligament, the exiting nerve root can also be identified. The end-point of decompression is the exposure of the medial border of the contralateral pedicle and restoration of dural pulsation. Adequate decompression may not be obtained if the medial side of the SAP is not exposed (Figure 4B). Furthermore, the authors advocate decompressing over 3 mm laterally from the lateral margin of the dural sac during continuous irrigation, because the dura shrinks under hydrostatic pressure. In contrast to the endoscopic view, the true lateral margin of the dura in its natural state may be located further laterally.

In a paraspinous approach, the lateral edge of the isthmus and the SAP tip are key structures. Using a Kerrison punch and drill, foraminoplasty is performed to decompress the neural structure and remove surrounding tissue. Then, the LF is

detached and removed using an angled curette to expose the exiting nerve root and perform discectomy and additional bone work to decompress the neural structure. When soft tissue is dissected, the transverse process, isthmus, and facet joint are exposed. In the case of a hypertrophic facet joint, removing the SAP cranial tip with a diamond drill or osteotome to create sufficient space facilitates safe surgery. If the SAP tip is not removed sufficiently because of concerns regarding instability, the surgery becomes more difficult; therefore, it must be removed adequately. Even if the SAP tip is removed sufficiently, instability is not caused generally, but further study is required



**Figure 4.** (A) Compared to conventional open surgery, bilateral decompression through the contralateral sublaminar approach (yellow arrow) in unilateral biportal endoscopic spinal surgery is a method to minimize the laminectomy area (yellow area). Compared to the preoperative magnetic resonance imaging (MRI) (B), the postoperative MRI (C) showed that the neural structure was well decompressed with minimal laminectomy. Adequate decompression may be obtained after the medial side of the superior articular process is exposed.

to confirm this. Discectomy is performed using a pituitary rongeur, curette, etc. Additional discectomy, often from the axilla region of the exiting root, may now be performed if the offending pathology is a herniated lumbar disc. In the approach at the L5/S1 level, drilling is first performed on the base of the L5 transverse process and the cranial and lateral sides of the SAP. If the SAP is too deep and too steep, it is difficult to access with a drill, so an angled instrument, such as a hockey stick chisel and an angled pituitary clamp can be useful. In obese patients, a 30° scope may be helpful rather than a 0° scope. Depending on the conditions, removing the sacral alar can be an important procedure for creating sufficient surgical space. To perform an L5 exiting root decompression and discectomy safely, sufficient space must be obtained. When the bone work is done, remove the LF using a Kerrison punch or curette. When anatomy is confused, discography can help to identify the anatomy. Some surgeons do not perform enough SAP resection because of the concern that excessive SAP removal could lead to instability in patients. However, this may lead to insufficient neural decompression and continued symptoms. According to biomechanical studies, resections of less than 75% do not result in segmental instability [14,15].

In far-out syndrome decompression, an endoscopic drill is used after exposing the lateral aspect of the SAP, the sacral alar, and the lower border of the transverse process. Bleeding occurs as the cancellous bone is exposed at times and bleeding should be controlled using an RF probe or bone wax. During the procedure, pseudo-articulation is identified and should be removed laterally as much as possible. After removal, the foraminal ligament covering the exiting nerve root must be checked and sufficiently removed. The LF attached under the transverse

process should be detached and safely removed using a small Kerrison punch, angled curette, etc., and the exiting nerve root below this is checked. The annulus of the intervertebral disc can be identified and, if necessary, ventral decompression can be performed through discectomy.

Discectomy varies slightly depending on the location of the lesion and the characteristics of the disc. Generally, a retractor is used to sufficiently protect the root during discectomy, then an annulotomy is performed using an Indian knife, etc., and removal of the disc using pituitary forceps. Calcified discs are removed using a Kerrison punch or osteotome. During a discectomy, the nerve should be protected continuously, and it is also helpful to use scope retractors and assistant retractors. Expose the disc space by carefully performing dura retraction on the disc on the contralateral side as well as the ipsilateral side, and remove it using an angled hook, small pituitary forceps, and an angled upbite pituitary. Epidural bleeding control and annuloplasty should be performed using an RF probe, and the power of the RF probe must be lowered near the dura (Table 2) [16-18]. Also, to reduce traction injury, it is important to perform root release intermittently. To reduce recurrence, internal disc decompression and nucleus pulposus must be adequately removed using an RF probe and annuloplasty is also performed.

Decompression in posterior thoracic surgery is comparable to decompression in lumbar surgery. The difference is that cord injuries must be avoided. The thoracic spinal canal is narrower than the lumbar spinal canal, the lamina is short and thick and overlaps the cranial and caudal lamina. Therefore, when bilateral decompression is performed through the unilateral approach, there is a high risk that the endoscope and working in-

**Table 2.** Recommended energy parameters for radiofrequency application

The energy parameter (based on a DELPHI radiofrequency device)	Ablation	Coagulation
Around the bone	7	2
Epidural space	3	1
Around the thecal sac	x	1

DELPHI radiofrequency device (C&S Medical Inc., Pocheon, Korea).

struments excessively compress the cord, resulting in a thoracic cord injury. Therefore, it is necessary to sufficiently remove and undercut the base of the spinous process to expand the working space more than when performing lumbar surgery. To avoid neural injury during thoracic surgery by UBE, the LF is left in place as protection until all bone work is complete. Until the lateral edge of the thecal sac is checked out, which is naturally confirmed through epidural fat tissue, the remaining medial border of SAP (ipsilateral and contralateral) can be removed. The medial side of the facet joint, with as much remaining as possible for stability, overlaps the lateral end of the laminectomy. The 3 key steps in thoracic OLF removal are thinning, detaching, and removal. OLF is difficult and risky to remove with a Kerrison punch. When removing the OLF, it is important not to apply unintentional compression to the spinal cord. After exposing the OLF, the operator grinds until it is thin and translucent using a diamond drill. The thinned OLF should be detached from the thecal sac using a freer elevator and gently removed. If necessary, remove it piece by piece using a 1-mm Kerrison punch or small-sized pituitary forceps. If OLF removal fails due to dural ossification or severe adhesions, the floating method is a good alternative, leaving the OLF on the thecal sac. Above all, an important surgical tip is to experience sufficient lumbar spine surgery before thoracic spine surgery with UBE.

In posterior cervical foraminotomy surgery, partial laminectomy and facetectomy are performed at the V-point using a 3.5-mm diamond burr. Before using a drill, the V-point of the targeted lamina should be checked. The drill is used in the craniolateral direction from the inferolateral portion of the cranial lamina until the LF is detached. From the superolateral part of the caudal lamina, the bone is made thin in the caudolateral direction and is drilled until the dura is identified. According to the size and height of the pathologic lesion and level, the area of the foraminotomy can be extended to the lateral or craniocaudal side. It is possible to remove one-third to one-half of the medial side of the facet joint. However, if more than 50% of facet joint is removed, there is a substantial risk of instability. After flavectomy, the medial border of the pedicle and the dura

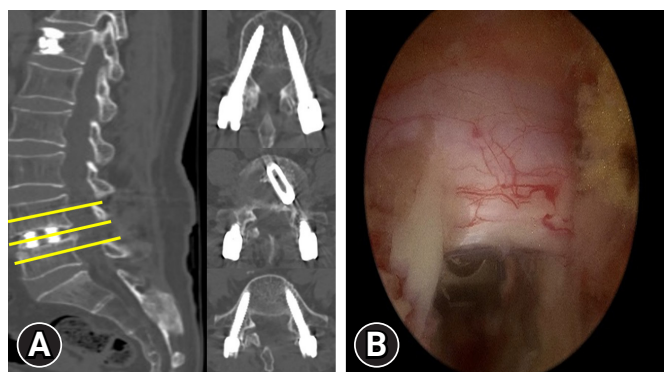
and exiting nerve root should be checked. Once the exiting nerve root is identified, foraminal decompression is performed using a 1-mm Kerrison punch. If a protruded disc is visible around the nerve root, it is removed gently. If the workspace is narrow, a pediculectomy can be used to create enough space while reducing nerve root manipulation. Finally, the lateral edge of the pedicle should be checked to ensure appropriate foraminal decompression via the neural foramen using a ball-tip type hook. All surgical procedures should be performed safely to prevent spinal cord injury.

## 5. Unilateral Biportal Endoscopic Lumbar Interbody Fusion

In contrast to general decompression, it is not recommended to perform laminectomy using a drill during unilateral biportal endoscopic lumbar interbody fusion (ULIF). Local autobone can be collected for bone grafting by laminectomy using a Kerrison punch or osteotome. The inferior articular process is also removed and should be resected in several pieces because it may be difficult to remove through the working portal if it is resected in large pieces. Contralateral facetectomy performed across the base of the spinous process is helpful for spondylolisthesis reduction or correction of a lordotic curve. If the contralateral facet joint osteophyte is larger or to achieve greater reduction or greater lordotic curve in spondylolisthesis, a total facetectomy is performed by additionally making incisions on the contralateral side. These skin incisions are necessary even for percutaneous screw insertion on the contralateral side (Figure 5).

The medial aspect of the SAP should be removed sufficiently to enable interbody cage insertion. If it is not sufficiently removed, excessive neural structure retraction may occur during cage insertion. A space of at least 8 mm from the lateral margin of the thecal sac must be maintained to insert the cage safely. The ipsilateral exiting nerve root should not be fully exposed before cage insertion to protect it during cage insertion. Angled endplate removers and pituitary forceps are used to remove the nucleus pulposus and cartilaginous endplate. Endplate preparation is completed on both the ipsilateral and contralateral sides using an angled endplate remover, which is essential for fusion. It is helpful to use a 30 degrees endoscope for endplate preparation to the contralateral side. During surgery on patients with high-grade spondylolisthesis or significant disc narrowing, the upper edge of the caudal vertebral body is removed with an osteotome to make a larger entry. By magnifying the endoscopic view, surgeons can determine when the endplate





**Figure 5.** Postoperative sagittal and axial computed tomography images (A) and intraoperative endoscopic images (B). One transforaminal lumbar interbody fusion cage was inserted through the left side only, and percutaneous pedicle screws were inserted through 4 incisions, including 2 portal incisions.

preparation is complete. To prevent bone graft loss during cage insertion, continuous irrigation should be paused. Before cage insertion, dilate the paraspinal muscles with a bar dilator to make it easier for cage insertion. Anchor to the caudal vertebral body edge with a specialized root retractor, and insert the cage into the annulotomy site with gelfoam to reduce bone graft loss and bleeding. After cage insertion, a foraminal decompression is performed by removing the foraminal ligament around the exiting nerve root on the ipsilateral and contralateral sides. If good pulsation of the nerve root and thecal sac is identified, it can be regarded as the endpoint of decompression. Perform percutaneous pedicle screw fixation using 2 ipsilateral and contralateral skin incisions. The distance between the exiting nerve root and the traversing nerve root on the ipsilateral side is measured by preoperative MRI. If it is more than 16 mm, a large-sized cage can be safely inserted without neural injury. However, if it is less than 16 mm, a smaller cage may be needed.

Modified ULIF is similar to routine ULIF. A skin incision is slightly more lateral than in routine ULIF and uses 2 short posterior lumbar interbody fusion (PLIF) cages rather than one long transforaminal lumbar interbody fusion cage. Two PLIF cages are inserted into the unilateral laminectomy and facetectomy area. After adequately retracting the dura toward the medial side, the first cage is inserted into the medial or contralateral side. Using the cage pusher, after pressing slightly further to the contralateral side the second cage is inserted into the empty space remaining. A fusion material such as a bone chip is pushed between the 2 cages.

## 6. Closure and Postoperative Care

During surgical drain insertion, the drain is inserted blindly or under endoscopic guidance. If adequate bleeding control is completed, surgical drain insertion may be skipped. Because maintaining adequate saline flow during the drain insertion is important for the instrumental portal patency, a drain line should be inserted via the instrument rather than the endoscopic portal for a clearer surgical view. Compression around the portal before suturing may help to minimize soft tissue water retention. After the appropriate surgery has been completed, the muscle is approximated and the skin incision is closed with absorbable sutures or a sterile strip. The wound is covered with a sterile dressing, and the patient is sent to the recovery room. Patients are observed in a recovery room for several hours before being moved to a general ward. Provide analgesics as required and encourage patients to walk as soon as possible. Pain usually subsides within 24 to 48 hours.

## COMPLICATION AVOIDANCE

### 1. Postoperative Hematoma

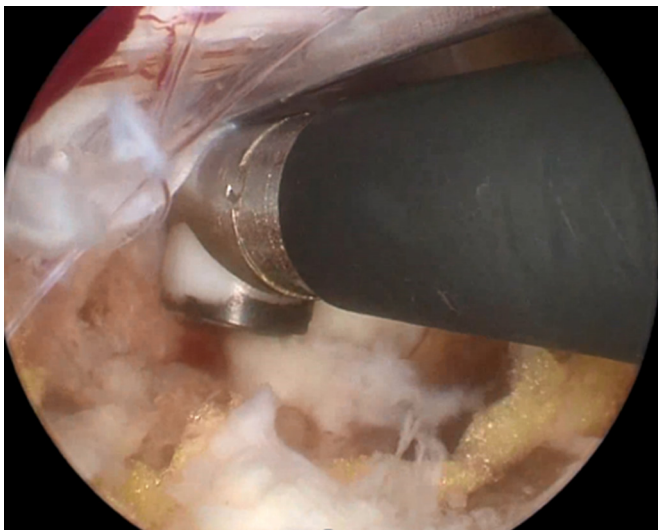
The most common cause of postoperative hematoma is inadequate hemostasis, which leads to an unsatisfactory clinical outcome after surgery. Postoperative hematoma may occur as epidural fibrosis, which can interfere with the expansion of the dural sac [19]. In addition to inadequate hemostasis, other risk factors for postoperative hematoma include sex (female > male), age (>70 years), history of anticoagulation medication, and usage in other preceding studies. It was found that the type of operation and water infusion pump (pressure: 30 mmHg, masking of epidural venous bleeding) had a significant effect [20].

Initial working space, bone bleeding, epidural vessels, and intramuscular bleeding are 4 key factors to consider when preventing postoperative hematoma. First, the possibility of postoperative hematoma is low when the initial working space maintains a clear view. To maintain a clear view, it is necessary to check prompt meticulous bleeding control and fluid output. Maintaining a systolic blood pressure between 90 and 110 mmHg during surgery is also helpful, as increased intra-abdominal pressure leads to increased bleeding. One of the major causes of postoperative hematoma is bone bleeding, which is common in patients with osteoporosis. Bone bleeding seems to be reduced due to hydrostatic pressure, but when the hydrostatic pressure decreases, bone bleeding appears. There-



fore, bone wax and an RF probe should be used carefully to control the bleeding. In a previous study comparing UBE and conventional discectomy, a postoperative epidural hematoma was reported in 8.5% of UBE and 1.4% of conventional surgery, which is due to hydrostatic pressure caused by the masking of bleeding [21]. The routine application of bone wax to the spinous process base, cranial and ipsilateral sides is recommended. However, areas where bone work has been performed using an osteotome and Kerrison punch are not flat; therefore, bone wax cannot be applied well in these areas. After flattening with a burr, the application of bone wax can be helpful [22].

RF is used to control bleeding in patients with highly abundant epidural vessels. When controlling bleeding, always create a space between the dura and the epidural vessel and coagulate in the opposite direction with the neural structure at the rear (Figure 6). In focal bleeding, a hook-type RF is used, and in epidural bleeding where the focus is not visible, gelfoam and Gelatin-Thrombin Sealants (FloSeal, Baxter Healthcare Corp., Fremont, CA, USA) are used. To control the bleeding that occurs when LF is removed, *en bloc* should be used. Before removing LF, the margin can be coagulated with RF and then removed with *en bloc*. Occasionally, if there is bleeding from the endoscope portal rather than bleeding within the surgical field, there may be artery bleeding of the muscle, which should be confirmed and coagulated. When bleeding occurs at the endplate during ULIF, cage insertion is a method to prevent



**Figure 6.** The neural structure is located on the back of a radiofrequency (RF) device to protect the nerve during coagulation. If RF is used for a long time, the likelihood of nerve damage is increased. Therefore, completing bleeding control in a short time can prevent neural injury.

bleeding. If bleeding is so severe as to interfere with the surgery, the endoscope can be advanced as close as possible to the suspected bleeding focus. To find the bleeding focus, the hydrostatic pressure is increased temporarily to wash out and coagulate the bleeding using a small-size RF probe. A drain after surgery is another effective method of preventing postoperative hematoma. If bleeding from the extraforaminal area is not controlled, inserting a drainage catheter into the foraminal space can prevent postoperative hematoma and retroperitoneal hematoma [23] (Supplementary video clip 2).

In a paraspinous approach, hematoma and irrigation fluid may accumulate in the abdominal space after surgery, so the procedure should be performed without using an infusion pump or using a working sheath (Figure 3). In addition, the transverse process should not be removed excessively; hematoma and irrigation fluid will infiltrate the abdominal space if the transverse process is removed more than necessary. In L5/S1, the lower sacral alar is resected instead of the transverse process, and the upper pathologic foraminal ligament should be removed finally to prevent hematoma and irrigation fluid from entering the abdominal cavity. Occasionally, radicular arterial bleeding can cause many difficulties in performing surgery by obscuring the endoscopic visual field due to massive bleeding. The best way to prevent this is to coagulate the small vessels using the RF probe before bleeding occurs.

An important key to preventing bleeding in posterior cervical surgery is the position of the patient. By sloping the upper back downward, the venous return can be decreased. Using this technique can significantly reduce intraoperative bleeding. When the vertebral artery is medially located during cervical foraminotomy, extreme RF power may cause injury to the vertebral artery. Gelfoam or Gelatin-Thrombin Sealants should be used if bleeding occurs during foraminotomy. Since there are many vessels in the periradicular fibrous sheath, it must be removed while coagulating with a hook RF [24]. In cervical surgery, the *en bloc* removal of LF can help prevent postoperative hematoma, and even if postoperative hematoma occurs, it can be removed under local anesthesia.

## 2. Dura Tear and Traction Injury

A dura tear is the most common complication (1.9%–8.6%) in UBE and occurs most frequently in the thecal sac, axillar, traversing root [25]. The causes of dura tear are unpracticed handling, lack of understanding about water dynamics, adhesion, massive bleeding (blurred vision), blind procedure, Hemo-vac-drain tip irritation, repeated damage by a sharply face-

tectomized site (remaining bone edge), etc. ([Supplementary video clip 3](#)). In endoscopic spine surgery, hydrostatic pressure causes central folding, and beginners have a high risk of tearing the dura because the working space is frequently restricted in inexperienced surgery [26]. In addition, dura tears often occur on the dural sleeve, and to solve this problem, the working space should be expanded through sufficient bone work and dura repair should be attempted. A dura tear can occur when experts perform blind techniques carelessly or when additional bone work is performed close to the exposed dura after the LF has been removed. The meningovertbral ligament is responsible for pulling the dura back, so this is not confirmed and there is a high possibility of making a dura tear during the removal of various epidural tissue ([Supplementary video clip 4](#)).

In incomplete decompression, the facet joint remains sharp (remaining bone edge), which is the reason for delayed dura tear after surgery. Therefore, the medial facet joint should be wide decompressed and the surface should not be sharpened. Unlike conventional surgery, the Hemovac drain is inserted vertically. Elderly patients may have a dura tear due to thin dura, or drainage catheter withdrawal after imaging because it can cause nerve root compression and cause radiculopathy. When a dura tear occurs, water pressure should be decreased to prevent increased ICP and simple observation with absolute bed rest is recommended for injuries less than 4 mm. For large dura tears of more than 12 mm, conversion to microscopic direct repair is recommended [25,27].

When a dura tear occurs, a surgical clip is used instead of a suture to perform a direct dura repair. In case of excessive tearing, a direct suture and repair are essential. When water and fibrin sealant come into contact, glue immediately becomes ineffective and hardens. Before delivering fibrin sealant, it is recommended that the Hemovac drainage catheter be opened and all irrigation fluid drained [28]. Removing the LF with enbloc rather than with piecemeal helps to reduce dura tears because unnecessary procedures on the dura can be reduced. When performing bone work after removing the entire LF, it is better not to use drilling, but to use a small osteotome or an angled Kerrison punch. A blurred surgical field can cause neural structure injury, so it is important to maintain a clear view of the surgical field, such as active bleeding control, and since the RF probe can cause neural tissue injury, its use should be reduced around the neural structures as much as possible.

## CONCLUSION

The field of UBE has achieved remarkable advancements in

recent years, and endoscopic techniques have become common essential spinal surgery procedures. This literature review describes essential surgical techniques during UBE, not only for beginners but also for those with established skills.

## NOTES

### Supplementary Material

Supplementary video clips 1-4 can be found via <https://doi.org/10.21182/jmisst.2023.00871>

**Supplementary video clip 1.** Smooth saline flow created by using working sheaths.

**Supplementary video clip 2.** Bleeding control techniques during unilateral biportal endoscopic spinal surgery. Radiofrequency (RF) device, bone wax with or without RF, Gelatin-Thrombin Sealants (Floseal, Baxter Healthcare Corp., Fremont, CA, USA), and Hemovac insertion.

**Supplementary video clip 3.** A dura tear caused by using a cutting instrument without sufficient dissection.

**Supplementary video clip 4.** The meningovertbral ligament is responsible for pulling the dura back, so meningovertbral ligament is not confirmed and there is a high possibility of tearing the dura during the removal of various epidural tissue.

### Conflicts of Interest

The authors have nothing to disclose.

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# Single- and Multiple-Segment Percutaneous Pedicle Screw-Rod Fixation: Complications and Bailout Strategies

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Percutaneous pedicle screw fixation systems have improved significantly since their introduction in 2001. A new surgeon's learning curve is usually 70 cases when defined by the complication rate and not by a specific time to insertion. An appropriate preoperative assessment is important when considering a percutaneous pedicle screw approach, and high complication rates are linked to patients above the age of 65 and the need for multilevel fixation. A surgeon should be wary of performing surgery at the wrong site; therefore, meticulous documentation should be carried out, and the operative level should be confirmed. During surgery, attention should be paid to positioning the patient and varying the location of the skin incision depending on the patient's obesity. Penetration of visceral structures and vessels due to guidewire insertion is not an uncommon complication. Anterior penetration of the guidewire by as little as 5 mm can cause significant sympathetic chain dysfunction. Guidewire removal should also be prevented during tapping of the screw hole and removal of the Jamshedi needle. This procedure has a high complication rate in unexperienced hands and should be performed by surgeons after adequate cadaver training. Surgeons should initially attempt only single-level fixations and then later on move to more complex multilevel fixations and deformity corrections.

**Key Words:** Spine, Deformity, Pedicle screw, Complications

## HISTORY OF AND COMPLICATIONS ASSOCIATED WITH PERCUTANEOUS PEDICLE SCREW FIXATION SYSTEMS

The first percutaneous pedicle screw (PPS) insertion was reported in Berlin, almost 40 years ago, albeit for an external fixator application [1]. Although a fully percutaneous system with a subcutaneous rod arrived in 1995 [2], the commercial availability of the PPS system would not occur till 2001 when Medtronic launched their SEXTANT® system (Medtronic, Memphis, TN, USA), the use of which was reported by Foley et al. [3] in the form of case reports with its use limited to 1 or 2 level fixations

for degenerative disc disease.

However, since then there have been over 40 systems that have been in use spanning four generations developed by multiple companies [4] with a wide variety of indications including spinal fractures, long constructs in scoliosis, oncology, vertebral fractures as well as spondylosis [5-10].

Although the principle of minimizing damage to soft tissue during percutaneous placement of pedicle screws was retained, each newer generation of systems attempted to improve the learning curve for surgeons, decrease intraoperative complications, lessen operative time and expand indications for PPS fixation.



The first generation instruments like Sextant system and longitude 1 and 2 had a limited ability to correct spinal slippage and had heavy, easily detachable, and complicated extender assemblies that were attached to the screw head.

The second generation instruments like VIPER (Depuy, Chester, PA, USA), SEXTANT Advanced (Medtronic), MANTIS (Stryker, Portage, MI, USA), and ILLICO SE (AlphaTEC Spine, Carlsbad, CA, USA) allowed powerful reduction and linkage to navigation systems. Most modern instrumentations are largely based on the designs of these systems. Systems like the Ballista (Zimmer, Westminister, CO, USA) and SpiRit (Spirit Spine, Pasadena, CA, USA) that used ratchets showed promise in that they could provide parallel compression, however, in some cases the ratchet would get stuck, leading to the gradual abandonment of ratcheted devices in PPS systems.

The third generation systems were subtle modifications of the second generation with the introduction of a tab which was introduced through the extender which allowed a decrease in weight and easy removal of the extender. They also introduced lower profile 5- to 6-mm rods with titanium alloy which meant that they could be used in long constructed for deformity correction. The Medtronic Voyager ATMAS system (Medtronic) shows advancement over its Sextant predecessor (Medtronic) with a list of features including ability to link to an O-arm navigation system (Medtronic) as well as the Mazor X robotic system (Medtronic). The Bendini spinal rod bending system (Nuvasive, San Diego, CA, USA) that complements PRECEPT (Nuvasive) and RELINE systems (Nuvasive) allows predictable and reproducible patient specific rod bending preventing high loads at the screw bone interface.

The latest generation (fourth generation) works aims to decrease operative time by allowing a guide wire free placement of pedicle screws. It therefore does away with the use of Jamshidi needles, bone tunnel creation, guidewire positioning, use of a dilator, and tapping, however as the PPS that is inserted is sharp tipped, there have been some problems in re-inserting the screw [4].

## LEARNING CURVE AND COMPLICATIONS OF PPS FIXATION

The concept of learning curves, originally introduced in the aircraft industry in 1936 [11] and defined for the surgical community by the British Royal Infirmary inquiry [12] as recently as 2004, which in the context of surgery is defined as “the time taken and/or the number of cases required by an average surgeon to become proficient (e.g., reduce operative time, estimated

blood loss, and morbidity/adverse events) to be able to perform a procedure independently with a reasonable outcome.”

The factors affecting this learning curve in minimally invasive (MIS) spine surgery have been well defined by Sharif and Afsar [13] and include surgeon proficiency, progressive training arrangements, progressive procedure advancements as well as hospital equipment and staff support. Minimally invasive spine surgery and therefore PPS may pose a challenge to surgeons in terms of limited visualization and lack of traditional landmarks and therefore MIS/PPS is said to have a shallow learning curve [14,15], meaning the proficiency of the surgeon in the procedure does not markedly increase with an increase in the number of procedures (Steep learning curves are actually better than shallow ones).

Although the risk of complications in MIS decompression surgeries dropped by almost 100% after the initial 30 cases with no effect on outcomes between the initial and latter cases, the evidence for a pedicle screw fixation is not quite the same [15,16].

Silva et al. [17] in a 150 patient cohort of 1-/2-level MIS transforaminal lateral interbody fusion showed only a 50% improvement in proficiency by case 12 and 90% by case 39 with the complication rate being as high as 33% till case 12 and 20.5% till case 39. However, the ‘proficiency’ in this case was only assessed with help of mathematical models based solely on operative time. A more accurate representation of the learning curve would be through analysis of pedicle violation, interpedicular orientation etc. during initial cases of a surgeon as done by Landriel et al. [18] who found that the violation of the pedicle wall in their cohort of surgeons new to the technique was most commonly at L5 and the cause of these violation was a bad entry point in 48% cases and incorrect angulation in 52% cases. They concluded in their study that 70 PPSs needed to be placed to achieve a breakout rate as low as that of experienced surgeons, which in single level cases would be 70 cases, much higher than that reported by Silva et al. [17] However, with the use of 3rd/4th generation instruments combined with robotics, recent evidence [19] suggests that the learning curve is being shortened and accurate placement of pedicle screws would get easier earlier in the surgeons career. Use of cadaver training can also prove to be an effective tool to fight the learning curve for this procedure by placement of the first 70 screws in these spines.

## PREOPERATIVE CONSIDERATIONS AFFECTING COMPLICATION RATE

Since, as mentioned above, the perioperative rate even late



in the learning curve may as high as 21%, identification and optimisation of the independent risk factors that predispose patients to perioperative complications of PPS fixation becomes paramount [20-23].

Jenkins et al. [21] reported that an age of more than 50, obese status of a patient and preoperative diagnosis of diabetes mellitus were the only significant patient characteristics that affected complication rate. There was no bearing of the smoking status, hypertensive status, preoperative visual analogue score, American Society of Anesthesiologists physical status classification grade or Charlson Comorbidity Index on the postoperative complication rate. However, since the rate of major technique associated complications including neurological dysfunction (0%) and durotomy (0.5%) were low, the effect of these factors on major complications cannot be assessed accurately. Another study by Claus et al. [22] directly contradicts the findings above by suggesting that morbid obesity (body mass index  $>40 \text{ kg/m}^2$ ) was not associated with either objective outcomes, postoperative complications, readmissions or adjacent segment disease. A pooled meta-analysis by Huang et al. [24] of 12 studies suggested that patient age ( $>65$  years) and multilevel fixation were independently linked to higher major and minor complication rates, however, with no effect on objective patient reported outcomes.

Outcomes in patients compromised by these negatively associated factors will be dependent on the surgeon's experience and it is best therefore to limit oneself to single level PPS fixation in younger, nonobese patients in early days with progression to more complex indications and multilevel fixation with increased experience.

## OPERATIVE CONSIDERATIONS

### 1. Level of Surgery

Mody et al. [25] reported that almost 50% of surgeons admitted to performing surgery at the wrong level at some point in their career making it imperative to address this challenge of wrong level MIS surgery. The most common site of wrong level surgery was lumbar followed by cervical spine [26]. Multiple protocols have hence recommended the 3 R approach (right patient, right side and right level), Timeouts and marking the correct side to avoid wrong level and side surgery [26,27]. However, there continued to be incidence of wrong site/level of surgery with ineffectiveness of these protocols [28].

To try and battle these challenges, some authors have suggested placement of fiducial markers under computed tomog-

raphy (CT) scan or fluoroscopic guidance under conscious sedation of the patient in the outpatient setting [29,30]. One must also always be aware of the anatomical variations that could lead to surgery at the wrong level as described by Shah et al. in their papers [31,32].

### 2. Positioning

Appropriate positioning includes attention to maintenance of physiological curvatures, confirmation of smooth C-arm transition from the anteroposterior (AP) to the lateral positions and appropriate visualization of the target pedicles and avoidance of double imaging on the superior end plate of the vertebral body in AP position and double pedicle/posterior wall image in the lateral position [33]. Markings can be made on the operating room floor after patient positioning to guide the C-arm technician to the correct position of the C-arm unit if it has to be moved between AP and lateral positions in case of a machine with a narrow radius of curvature.

### 3. Skin Incisions

Although fairly straightforward for single level fixations, when attempting a multilevel fixation, incisions that are linearly arranged (in a straight line) prove to be helpful during rod insertion [34]. The incision lines for percutaneous placement in obese individuals should be more lateral by about 2 cm in the lumbar spine than they would be for a nonobese patient. This allows for decreased manipulation and tension over the skin and soft tissues [35]. For each screw incision, some authors recommend the use of 1% lidocaine with adrenaline to inhibit the nociceptive pathway and decrease bleeding [33].

### 4. Jamshidi Needle/Guide Wire Insertion

Jamshidi needles are used to carve out the trajectory in the pedicles, however, changing this trajectory can prove to be challenging with a straight needle and hence a beveled tip is preferred with allows subtle changes in trajectory [33]. Landriel et al. [33] also recommend the use of short and long handled Jamshedi needles in alternating spine segments to prevent obstruction of the surgeon's hand when changing trajectory. They also recommend that if a wrong path has been created by one Jamshedi needle with failed attempts to correct it, the needle in the wrong path can be kept there and a different Jamshedi needle should be used to create a new trajectory.

The technique of guide wire insertion for PPS has been well

illustrated by Mobbs et al. [34] in their technical paper. Complication of guide wire insertion ranges from 0.4% to 14.8% [36]. Types of complications can include K-wire fractures, cerebrospinal fluid (CSF) leaks [37], to infection [38], fractures of facets [39], bladder or visceral injuries, cardiac tamponade, retroperitoneal hematoma, etc. [36,40].

The guide wire can occasionally breach the anterior cortex when tapping or inserting the screw. This can lead to devastating complications. Mobbs et al. [40] divided this breach into minor (<5 mm), moderate (5–25 mm), and major (>25 mm). With a minor breach, the sympathetic chain (and its functions of ejaculation, temperature sensation and perspiration are under threat). A moderate breach risks injury to the major vessels (and associated risk of aneurysms, pseudoaneurysms, and retroperitoneal hematomas) and a major breach risks injury to the bowel and viscera. And therefore, it is important to prevent the anterior breach of the guide wire. These injuries can occur either due to fracture of guide wire and eventual migration or direct injury through a breached guide wire [36]. These complications are more often seen in both osteoporotic and obese patients [41] and are associated with increased operative time and intraoperative conversions from MIS to open procedures [42].

Therefore, surgeons should be cautious when inserted taps or screws over guide wires that a wide variation in the angle of insertion of the guide wire and the tap/screw can result in inadvertent migration or fracture of the guide wire [43]. Anterior breach can be prevented by sequential lateral images on fluoroscopy as the tap and screws are advanced on top of the guide wire and making sure that the guide wire does not penetrate beyond anterior one-third of the body [33]. The wire should be removed once the screw tip has entered the vertebral body.

Unintentional K-wire removal is often seen when removing the Jamshedi needle or the tap. This can be prevented by using a K wire, the end of which is long enough to be visualized at all times. It has been recommended that in cases of inadvertent removal of K wire, reinsertion through a free hand technique should be avoided as it is associated with high risk of dural injury [33]. Reapproach to the pedicle with placement of Jamshedi needle under fluoroscopic guidance should be done in these cases.

A bent guide wire should be removed immediately by levering it on the tap handle and removing it gently without sharp blows on the tap or screw. Fourth generation guide-wireless screws will also be helpful in preventing these complications. Any suspicion of major vascular injury has to be treated with abandonment of procedure and urgent CT angiography with a vascular consult for further assessment.

## 5. Screw Insertion

Some unique challenges have been described and some helpful tips have been suggested by Mobbs et al. [34] that would be useful for PPS fixation including:

- (1) Changing the direction of screw placement following initial cannulation of pedicle by a Jamshedi needle with the help of an undersized tap placed on a K wire. Using the tap to lever and change the direction to a more appropriate trajectory can be done, but one must be aware of the aforementioned risks of K-wire fractures
- (2) Placing of the S1 screw in a more inferior starting position to prevent the impingement of percutaneous retraction sleeves of L5 and S1 on each other.
- (3) Abandoning the PPS system for an open approach with a high-speed drill in case of sclerotic pedicles would prevent much frustration to the surgeon.

The issues relating to screw misplacement have already been mentioned and should be kept in mind especially during placement of the first 70 screws by a surgeon.

Zhao et al. [44] highlighted that lack of anatomical markers is a major factor for malposition of screws. They also recommended that in cases of CSF leakage, merely readjusting the position of pedicle screw could yield satisfactory results with open revision surgery with dura mater exploration and repair reserved for patients whose leakage is not alleviated post operatively.

Poor fracture reduction can be prevented by adequate pre-operative fracture type assessment and use of middle pedicle screws as forward driving points to for a strong string force for reduction and correction of kyphosis [45]. It has also been shown that single axis pedicle screws are more effective than polyaxial screws for fracture reduction [46].

## 6. Rod Insertion

Although quite straightforward for single segments, insertion of rods in multi-segment constructs can be challenging as removing rods after placement in PPS systems is difficult and therefore, a number of questions need to be answered before this step. As mentioned by Mobbs et al. [34], these questions should relate to the length of rod, appropriate bending of the rod, direction of insertion of rod and need of additional incision for insertion of rod. Mobbs et al. [34] recommended that length between retraction sleeves can prove to be an adequate

guide to rod length. To ensure easy passage of bent rods, the heights of the pedicle screws should be kept at an equal length throughout the construct and the rod should be introduced from that side of the construct where the pedicle screw is closest to the skin. However, Landriel et al. [33] suggest placement of rod from caudad to cephalad in kyphosis and cephalad to caudad in lordosis. They also recommended to lower the rod slowly and as parallel to the spine as possible to allow screw extenders to adopt their own angle. They also recommended to adjust the screws halfway in the construct and the superior and inferior distal screws would be last to be adjusted. They noted that alignment of the screw extender by force could lead to its breakage from the screw head and advised to lower all screw extenders simultaneously and progressively to reduce force in screw extender unions.

Although it is recommended to prevent un-evenness of screw heads in the lateral projection, a high-grade spondylolisthesis at L5-S1 may prevent this and cause intraoperative complications. This can be tackled, as mentioned by Landriel et al. [33] by use of an interbody cage to initially reduce the listhesis and if the indented alignment persists, a longer screw should be used in L5 to allow matching of the height of the screw heads.

New techniques of computer assisted rod bending system have shown to avoid screw pull out and loosening postoperatively and can be used to minimize such complications [47].

## 7. Placement of Inner

If the screw extender detaches from the screw head while placing the inner, a wider incision can be taken, soft tissue retracted and the inner can be placed under direct vision after confirming the rod has passed through it.

## CONCLUSION

Minimally Invasive Approach to pedicle screw placement has its fair share of complications and identification of factors that cause and utilization of techniques that prevent these should be actively sought by the surgeon. Although challenging in the initial phase of a surgeon's career, appropriate patient selection and adherence to guidelines can help with desired outcomes.

## NOTES

### Conflicts of Interest

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# Clinical and Radiological Outcomes of Spinous Process-Splitting Laminectomy for Lumbar Spinal Stenosis at 1 Year: A Preliminary Report of a Single-Institution Experience

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**Objective:** This study investigated the clinical and radiological outcomes of lumbar spinous process-splitting laminectomy (LSPSL) performed to treat lumbar spinal stenosis at a single institution in Korea.

**Methods:** A retrospective review was conducted of patients who underwent LSPSL for lumbar spinal stenosis between June 2020 and February 2022, with a minimum 1-year follow-up. Clinical outcomes were assessed using the visual analogue scale (VAS), Oswestry Disability Index (ODI), European quality of life - 5 dimensions - 5 levels (EQ-5D-5L), European quality of life VAS (EQ-VAS), and modified MacNab criteria. One year after surgery, radiological outcomes were evaluated through computed tomography scan to assess the spinolaminar bone union rate and patterns.

**Results:** Out of 38 patients, data from 30 patients (male:female = 17:13) and 36 surgical levels were analyzed. The mean age was 67 years (range, 46–88 years). The preoperative mean leg VAS score and ODI significantly decreased at the 1-year postoperative follow-up (leg VAS, 6.6–3.8;  $p=0.001$ ; ODI, 19.3–10.9,  $p=0.006$ ). The EQ-5D-5L index and EQ-VAS also significantly improved (0.52–0.77,  $p<0.001$ ; 50.8–67.1,  $p=0.018$ ; respectively). Using the modified MacNab criteria, the study reported excellent and good outcomes in 80% of patients at the 1-year follow-up, with no serious complications observed. The overall spinolaminar union rate was 77.8% (complete union, 58.3%; partial union 19.4%).

**Conclusion:** LSPSL was found to provide favorable clinical outcomes and a satisfactory rate of posterior bony structure restoration for lumbar spinal stenosis, making it a feasible treatment option.

**Key Words:** Lumbar vertebrae, Degenerative, Laminectomy, Outcome; Spinal stenosis; Spinous process splitting

## INTRODUCTION

Lumbar spinal stenosis is characterized by the narrowing of the lumbar spinal canal, which can compress the nerve roots.

This condition can cause various symptoms including sensory changes, pain in the back and legs, neurogenic claudication, and even motor weakness of the legs. Initially, conservative managements options such as lifestyle modification, medica-

tion, physiotherapy and spinal injections are considered [1]. However, if conservative treatments fail to provide relief, surgery to decompress the spinal canal is recommended [1,2].

Conventional laminectomy is a surgical procedure to treat lumbar spinal stenosis by removing the entire lamina and, situationally, a part of facet joints or ligamentum flavum [3]. While conventional laminectomy can effectively relieve spinal stenosis, this technique is associated with several disadvantages. The removal of the spinous process and the detachment of paraspinal muscles pose potential risks for postoperative spinal instability which can result in persistent back pain and additional spinal deformity [4-7].

Several surgical techniques have been developed to overcome the shortcomings of conventional laminectomy. Among them, lumbar spinous-process splitting laminectomy (LSPSL) was first introduced by Watanabe et al. [6,7] and modified by Nomura et al. [8]. This procedure preserves the integrity of spinous processes and maintains the attachment of the paravertebral muscle insertion. By preserving posterior supporting structures, LSPSL minimizes tissue disruption and postoperative morbidities [9].

LSPSL has demonstrated fair clinical outcomes, but not much data regarding the clinical and radiological outcomes of this approach is available in Korea. This study aims to analyze 1-year clinical and radiological outcomes of patients who underwent LSPSL surgery for lumbar spinal stenosis.

## MATERIALS AND METHODS

Between June 2020 and February 2022, patients who received LSPSL surgery for degenerative lumbar spinal stenosis by a single surgeon (SL) at Samsung Medical Center were retrospectively reviewed. Institutional Review Board (IRB) approval was obtained for this study (IRB No. 2023-06-060) and informed consent was waived due to its retrospective nature.

We included patients who had a minimum of 1-year follow-up. Patients with missing medical records and radiographic images during the follow-up period, and those who underwent LSPSL for conditions other than degenerative spinal stenoses, such as herniated intervertebral disc, epidural abscess, and intradural tumors, were excluded. Patients with radiographic instability at the index level or more than grade 2 spondylolisthesis were also excluded. Basic demographic data, the level of operation, postoperative hospital stay, operation time, estimated blood loss during surgery, and follow-up period were collected by reviewing the patient's medical records. Preoperative evaluation included anteroposterior, lateral, flexion and

extension simple radiographs, computed tomography (CT) and magnetic resonance imaging (MRI) of the lumbar spine for every patient.

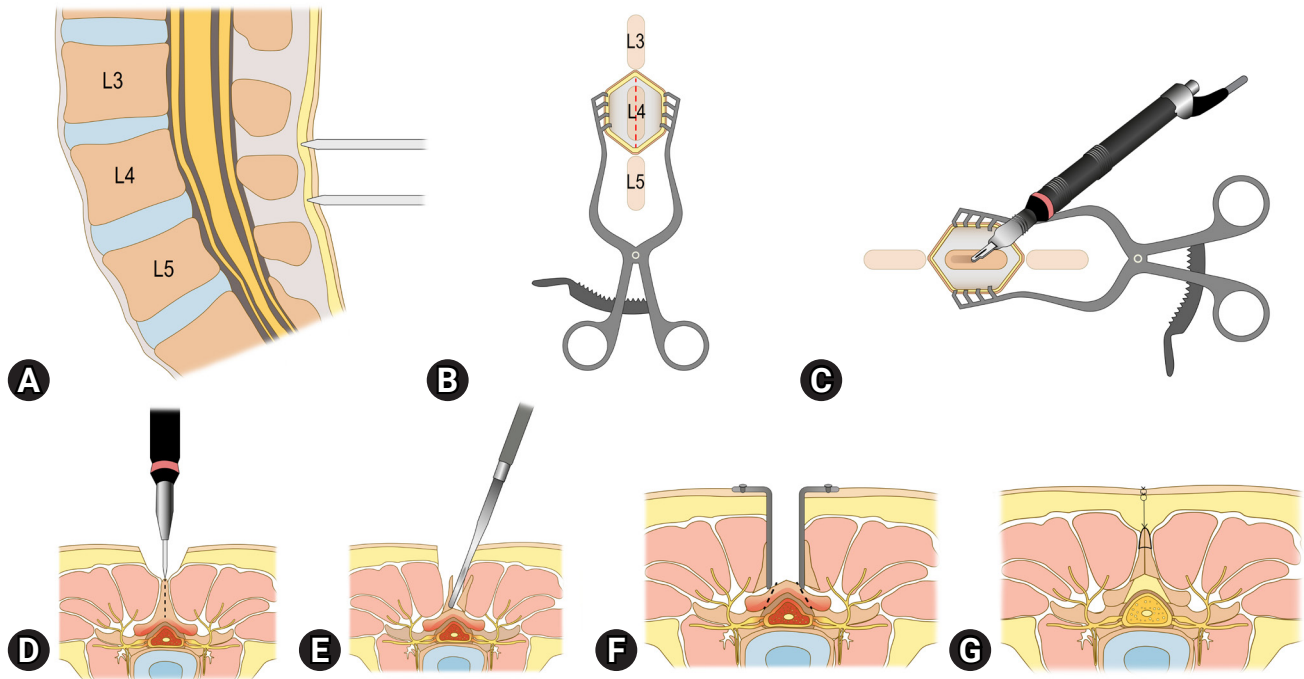
During the study period, 55 patients underwent the LSPSL procedure. Out of these, 10 patients received LSPSL for a herniated lumbar intervertebral disc, and 1 patient underwent the procedure for a tumor. As a result, these 11 patients were excluded from the study. Additionally, 14 patients were excluded due to missing medical records, radiographic images and the necessary follow-up. Consequently, 30 patients were included in this study.

### 1. Surgical Procedures: Lumbar Spinous Process Splitting Laminectomy

Figure 1 illustrates the surgical procedure of the lumbar spinous process splitting laminectomy. All surgeries were performed under general anesthesia. Patients were positioned prone, and we primarily utilized the Wilson frame to flex the patients' lumbar spine, thereby widening the surgical corridor. Confirming the location of the index spinous process by a simple lateral radiograph is the first step (Figure 1A). A midline skin incision is then made (Figure 1B), followed by splitting the index spinous process (Figure 1C, D). For this splitting procedure, we predominantly used an ultrasonic bone scalpel (Bonescalpel, Misonix, New York, NY, USA), although a small-sized burr or a sagittal saw could be used with similar efficacy. After splitting the spinous process, its base is fractured from the lamina using a straight osteotome (Figure 1E). By spreading the floating, split spinous process laterally, both the left and right sides of the index lamina and interlaminar space are exposed (Figure 1F). Following sufficient decompression through partial laminectomy and flavectomy (Figure 1F), the split spinous process is reapproximated. The subcutaneous layer and the skin are sutured layer by layer to close the wound (Figure 1G).

### 2. Outcome Assessments

Back and leg pain scores were evaluated using the visual analogue scale (VAS) for the clinical assessment. The impact of the condition on daily functioning was assessed using the Oswestry Disability Index (ODI). The patients' overall quality of life was measured using the European quality of life - 5 dimensions - 5 levels (EQ-5D-5L) self-rating questionnaire, and the European quality of life VAS (EQ-VAS). These assessments were conducted at the preoperative stage and at the postoperative 3-, 6-, and 12-month follow-up periods.



**Figure 1.** Illustration of the lumbar spinous process splitting laminectomy procedure. (A) An intraoperative simple lateral radiograph is used to identify the location of the index spinous process. (B) A midline skin incision is made over the confirmed location of the index spinous process. (C, D) The index spinous process is split using an ultrasonic bone scalpel. (E) The spinous process base is fractured from the lamina using a straight osteotome. (F) Split, floating spinous processes are spread laterally to secure the surgical corridor and decompress the index level of stenosis. (G) After sufficient decompression, the operation wound is closed by reapproximating the split spinous processes and suturing subcutaneous and skin layers.

To calculate the EQ-5D-5L index, the Korean value set and the equation proposed by Kim et al. [10] were used. Furthermore, patient satisfaction and functional improvement after surgery were evaluated using the modified MacNab criteria.

Similar to the clinical assessment, radiological assessments were conducted at the postoperative 3-, 6-, and 12-month follow-up periods. Lumbar spine simple radiographs were evaluated during each of these postoperative periods to observe any changes in the spinal alignment of the lumbar spine. Additionally, at the 12-month follow-up, a CT scan with 2-mm thickness images was obtained. These images were used to assess the bony union rate and pattern between the lamina and the spinous process. We followed the fusion criteria and union pattern described by Wi et al. [11] (Figure 2). The union rate and pattern were further analyzed by dividing it into subgroups based on the number of decompressed levels.

### 3. Statistical Analysis

In this study, most demographic and radiographic data were

presented in descriptive statistics. The postoperative values of each clinical assessment were compared with the preoperative values using a t-test. When the distribution of a variable did not follow a normal distribution, the Mann-Whitney U-test was used. The significance level was set at  $p < 0.05$ . All analyses were performed using IBM SPSS Statistics ver. 27.0 (IBM Co., Armonk, NY, USA).

## RESULTS

A total of 30 patients who received LSPSL surgery for degenerative lumbar spinal stenosis were included in the final analysis. The patients' demographic data are summarized in Table 1. The mean age was 67 years (range, 46–88 years). There were 17 men and 13 women. Twenty-four patients underwent surgery for single level, 5 for 2 levels, and 1 for 3 levels. The mean postoperative hospital stay was  $5.2 \pm 1.6$  days (range, 2–10 days). The mean follow-up period was  $14.0 \pm 3.2$  months (range, 12–25 months).



**Figure 2.** Sagittal (left) and axial (right) computed tomography images taken at the postoperative 1-year follow-up showing (A) complete union between the split spinous processes and at the spinolaminar junction, (B) partial union (i.e., floated or one-side union) of the spinous process, (C) nonunion between the split spinous process and at the spinolaminar junction. The union and nonunion sites are marked with white arrows.

**Table 1.** Patient demographics (n=30)

Variable	Value
Age (yr)	67.0 ± 10.6 (46–88)
Sex, male:female	17:13
Body mass index (kg/m <sup>2</sup> )	25.0 ± 3.0 (19.3–31.5)
No. of operated levels	
1	24
2	5
3	1
Total number of operated levels	37
Level of operation	
L2–3	3
L3–4	10
L4–5	20
L5–S1	4
Postoperative hospital stay (day)	5.2 ± 1.6 (2–10)
Operation time (min)	
Per person	61 ± 18.1 (34–124)
Per level	49 ± 12.1 (20–105)
Estimated blood loss (mL)	
Per person	72.8 ± 67.2 (10–300)
Per level	56.1 ± 40.2 (5–200)
Follow-up period (mo)	14.0 ± 3.2 (12–25)

Values are presented as mean ± standard deviation (range) or number.

## 1. Clinical Assessments

The clinical outcomes are summarized in Table 2 and Figure 3. The mean VAS scores for leg pain, and ODI showed a statistically significant decrease after the operation, and remained consistent throughout the 1-year follow-up period (leg VAS, 6.6–3.8,  $p=0.001$ ; ODI, 19.3–10.9,  $p=0.006$ ). On the other hand, the mean VAS score for back pain showed a significant decrease at the postoperative 3-month follow-up (5.3–3.4,  $p=0.02$ ), but lost its statistical significance in the later follow-ups. The EQ-5D-5L indexes also showed statistically significant improvement after the surgery throughout the 1-year follow-up (0.52–0.77,  $p<0.001$ ). In addition, the EQ-VAS scores were sig-

nificantly improved in the postoperative 3- and 12-month follow-ups (50.8–69.8,  $p=0.004$ ; 50.8–67.1,  $p=0.018$ , respectively). According to the modified MacNab criteria, approximately 97% of the patients showed better than fair clinical outcomes at the postoperative 1-year follow-up (Figure 4).

## 2. Radiographic Assessments

Because CT scans of one patient who underwent 1-level LSPSL surgery for lumbar spinal stenosis were missing at the postoperative 1-year follow-up, 36 operated laminae were evaluated for the spinolamina fusion (Table 3). The postoperative 1-year follow-up CT scans showed a gross fusion rate of 77.8% (comprising 58.3% complete spinolamina union and 19.4% partial union). On the other hand, 22.2% of the operated laminae failed to achieve fusion. Among patients who underwent surgery for 1 or 2 levels, nearly 80% achieved fusion. In one patient who underwent 3-level decompression, only 1 level showed partial union, while the other 2 levels remained nonunion at the 1-year follow-up. However, owing to the lack of large patient samples, whether this finding had any significant difference could not be validated. Regardless of the state of fusion, none of the patients showed any changes in spinal alignment, such as an aggravation of lumbar kyphosis during the follow-up period.

## 3. Impact of Fusion on Clinical Outcomes

We classified patients into 2 groups based on their radiological outcomes: complete union, partial union versus nonunion. We then analyzed whether these groups had significant differences in clinical outcomes at postoperative 12 months. Three patients who underwent surgery involving 2 or 3 levels and had a mixture of complete union, partial union and nonunion outcomes at each level were excluded. The group categorized as

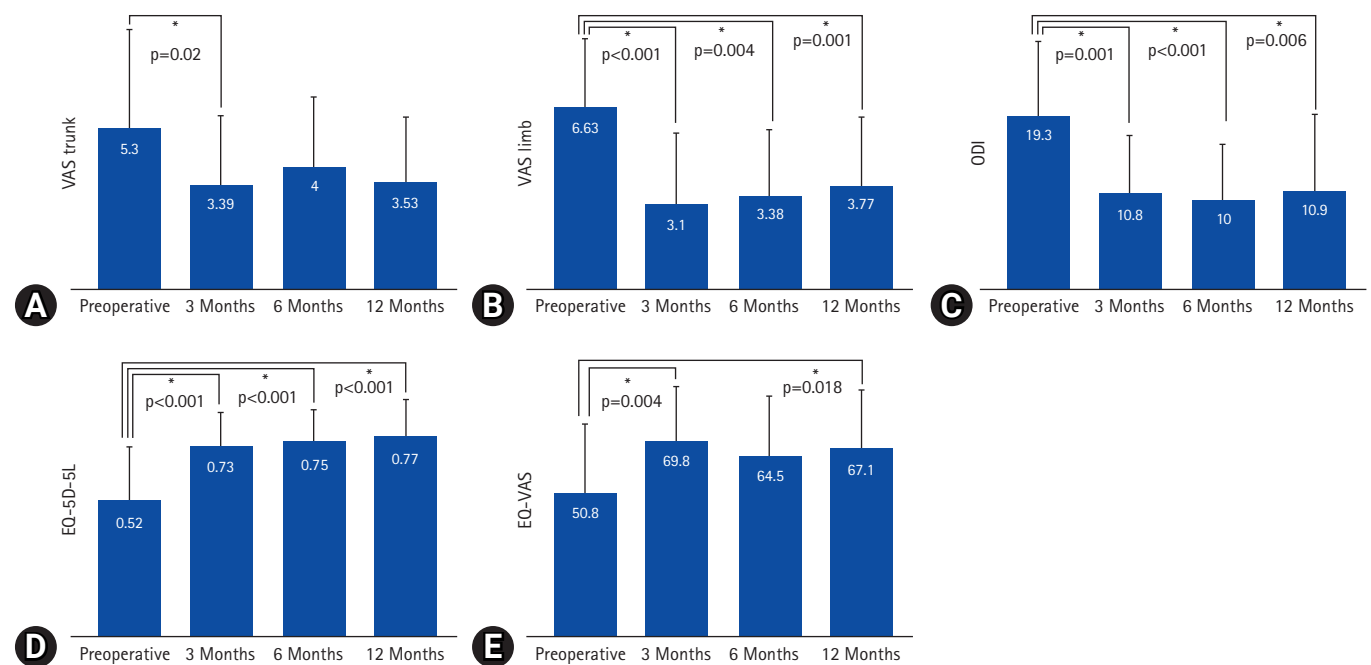


**Table 2.** Clinical outcomes (n=30)

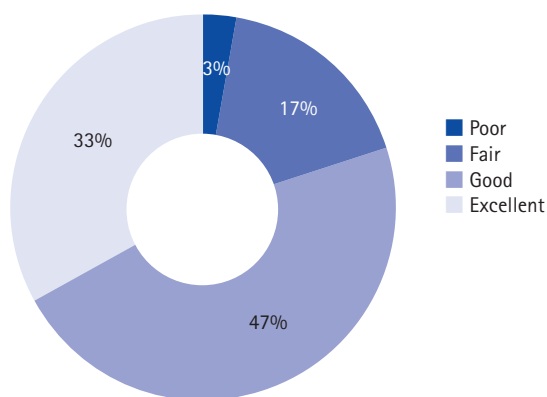
Variable	Possible range	Preoperative, mean $\pm$ SD	3 Months		6 Months		1 Year	
			Mean $\pm$ SD	p-value	Mean $\pm$ SD	p-value	Mean $\pm$ SD	p-value
VAS for back pain	0–10	5.3 $\pm$ 3.3	3.4 $\pm$ 2.3	0.02*	4 $\pm$ 2.3	0.12	3.5 $\pm$ 2.1	0.05
VAS for leg pain	0–10	6.6 $\pm$ 2.5	3.1 $\pm$ 2.6	<0.001*	3.4 $\pm$ 2.4	0.004*	3.8 $\pm$ 2.5	0.001*
ODI	0–45	19.3 $\pm$ 8.4	10.8 $\pm$ 6.4	0.001*	10 $\pm$ 6.2	<0.001*	10.9 $\pm$ 8.6	0.006*
EQ-5D-5L index	-0.07 to 0.88	0.52 $\pm$ 0.21	0.73 $\pm$ 0.13	<0.001*	0.75 $\pm$ 0.12	<0.001*	0.77 $\pm$ 0.14	<0.001*
EQ-VAS	0–100	50.8 $\pm$ 25.5	69.8 $\pm$ 20	0.004*	64.5 $\pm$ 22	0.05	67.1 $\pm$ 21.5	0.018*

SD, standard deviation; VAS, visual analogue scale; ODI, Oswestry Disability Index; EQ-5D-5L, European quality of life – 5 dimensions – 5 levels; EQ-VAS, European quality of life VAS.

\*p<0.05.



**Figure 3.** Preoperative and postoperative comparisons of clinical outcomes. (A) Back pain visual analogue scale (VAS) score, (B) leg pain VAS score, (C) Oswestry Disability Index (ODI), (D) European quality of life – 5 dimensions – 5 levels index (EQ-5D-5L), (E) European quality of life VAS (EQ-VAS).



**Figure 4.** Clinical outcomes at the postoperative 1-year follow-up using the modified MacNab criteria.

fusion and partial union included 22 patients, whereas the non-union group comprised 4 patients. There were no statistically significant differences among all of the clinical parameters: VAS for back pain ( $p=0.24$ ), VAS for leg pain ( $p=0.71$ ), ODI ( $p=0.32$ ), EQ-5D-5L indexes ( $p=0.09$ ), EQ-VAS ( $p=0.44$ ).

#### 4. Postoperative Complications

There were no serious complications related to the surgery. One patient who complained of grade 4 right ankle weakness and persistent pain 2 weeks after the surgery. A follow-up lumbar spine MRI revealed an epidural hematoma at the operation site. Given that the patient had a low platelet count (41 K) due

**Table 3.** Spinolamina union rates at postoperative 1-year follow-up (n=36)\*

No. of decompressed levels	Complete union	Partial union	Nonunion	Total
1	13 (56.5)	6 (26.1)	4 (17.4)	23
2	8 (80.0)	–	2 (20.0)	10
3	–	1 (33.3)	2 (66.6)	3
Total	21 (58.4)	7 (19.4)	8 (22.2)	36

Values are presented as number (%).

\*The computed tomography scan of 1 patient who underwent 1-level lumbar spinous process-splitting laminectomy surgery for lumbar spinal stenosis at the postoperative 1-year follow-up was missing. As a result, 36 laminae were used in the analysis, 1 less than the 37 laminae that should have been analyzed.

to hepatocellular carcinoma and liver cirrhosis linked to chronic hepatitis B, we opted for conservative management. This encompassed medication and physiotherapy. Three months later, the patient's symptoms had alleviated, and the motor power in his right ankle had been restored, all without additional treatments or subsequent complications.

## DISCUSSION

### 1. Clinical and Radiographic Outcomes

After LSPSL surgery, approximately 97% of the patients reported better than fair clinical outcomes at the postoperative 1-year follow-up according to the modified MacNab criteria. VAS for leg pain, ODI, EQ-5D-5L indexes, and EQ-VAS showed statistically significant improvements at the last follow-up. VAS for back pain showed statistically significant improvements at the postoperative 3-month follow-up, but lost its significance in the later follow-ups. However, a trend of improvement was noted during the follow-up period. Our results are broadly consistent with the reports in the literature. Cho et al. [12] reported that lower postoperative VAS scores were observed in the LSPSL group compared to the conventional laminectomy group. The muscle-sparing nature of LSPSL showed more favorable outcome, which were consistently observed at the 1-year follow-up. Some authors analyzed the recovery rate of the Japanese Orthopedic Association (JOA) score for clinical assessments [6,12]. JOA score in the LSPSL group was better but not all results met statistically significant results. Similar to our findings, Lee and Srikantha [13] reported a rate of 95% for better than fair clinical outcomes. They explained that the lower proportion of “excellent” outcomes in the elderly set of patients could be attributed to several factors beyond the direct outcome of surgery. Based on these results, we could conclude

that the overall clinical outcome of LSPSL surgery at the postoperative 1 year was favorable.

Determining whether the split spinous process and the lamina will recover structurally is important. The gross union was observed in most cases (77.8%). Complete restoration of the spinolaminar structure was observed in 56.5% of single-level surgery cases and 58.3% of the overall levels in the current study. This rate was higher than the original technique by Watanabe et al. [6] (32.9%) but somewhat lower than Nomura et al.'s technique [8] (82.7%). Wi et al. [11] reported a higher fusion rate in the partial spinous splitting group than in the complete spinous splitting group. Because our surgical technique incorporated Watanabe's total splitting method, this may be contributed to a lower rate of complete union compared to the results reported by Nomura et al. [8]. Because our study was a preliminary study with a small patient population, further research on a large scale is needed to investigate the higher fusion rate associated with partial splitting procedures.

In addition, it is important to determine whether spinolamina fusion affects patient clinical outcomes. Wi et al. [11] reported that no significant differences in the clinical results between patients who obtained complete restoration of the spinolaminar structure and those who obtained partial union or nonunion. Nomura et al. [8] reported that no direct evidence indicated that spinous process floating was associated with unfavorable clinical outcomes. Likewise, our study showed that the spinolaminar structure restoration did not show statistically significant differences in the clinical outcomes. However, by excluding patients with mixed results from multiple levels, there were insufficient patient numbers (4 cases) in the nonunion group. In addition, we have grouped complete and partial unions into 1 category, but it is unclear if they are equivalent. Therefore, further large-scale studies are needed to provide additional evidence in the future.

### 2. Advantages of Lumbar Spinous Process-Splitting Laminectomy

Because the conventional laminectomy technique utilizes extensive detachment of the paraspinal muscles, back muscle atrophy, chronic back pain, and even spinal instability can be occurred [14-22]. Several studies have conducted quantitative analyses of the paravertebral muscles using T2-weighted images before and after surgery [6,23,24]. Kanbara et al. [25] reported that in a 1-year follow-up, paravertebral muscle atrophy was lesser in the LSPSL group (7.8%) compared to the conventional laminectomy group (22.2%). In this study, the minimally in-

vasive nature of LSPSL, which preserves the back muscles, is believed to have contributed to favorable postoperative clinical outcomes.

Spinal instability after conventional laminectomy has been reported as a major complication [1,26-28]. It has been reported that preserving the structural integrity of the facet joint is beneficial in preventing vertebral slippage after surgery [28-30]. Compared to the LSPSL, midline structures disturb the access to the lateral recesses in bilateral laminotomy [2,6]. LSPSL offers symmetrical surgical visualization of the lateral recesses, and the risk of postoperative spinal instability resulting from excessive facetectomy can be minimized. Nomura et al. [8] also reported LSPSL did not accelerate postoperative slippage or instability of the vertebral body, which is well correlated with our study results.

Despite the benefits of the LSPLS [2], the LSPSL for lumbar spinal stenosis is less popular and less frequently performed compared to the unilateral laminotomy bilateral decompression. We conjecture that this is likely because surgeons are unsure of the benefits of LSPSL surgeries and find this technique cumbersome. In our opinion, the advantages of LSPSL surgery are as follows. First, the LSPSL technique is relatively easy to acquire. As Nomura et al. [8] pointed out, we experienced that this technique did not require a special learning curve. Compared to conventional laminectomy, the LSPSL technique involved a smaller incision while the surgical view was familiar and wide, providing more favorable clinical and radiological results. Second, in cases with severe facet hypertrophy, ipsilateral lateral recess, foraminal visualization, and decompression sometimes require a larger facet resection of the ipsilateral side, predisposing the spine to instability. Because LSPSL provides symmetrical surgical corridors from the midline, such risk could be lowered regardless of the degree of facet hypertrophy. Lastly, handling unexpected surgical complications is much easier in LSPSL. Especially when a dural tear occurs which is one of the common complications during minimally invasive spinal surgeries, primary repair is possible without additional exposure in most cases. Even if a surgeon did not start lumbar decompression surgery with the LSPLS technique, it is worth considering as a salvage technique in a complicated event.

### 3. Postoperative Complications

In our study, involving 30 patients undergoing surgery for 37 surgical levels, a self-limiting postoperative hematoma was observed in one case where the patient underwent surgery on a single level. The case of the patient occurred in the later part of

the study. Postoperative hematoma has been reported to have a complication rate of 0.8% to 1.4% when conventional laminectomy is performed [21,31]. There were no complications such as wound dehiscence or dura tear leading to cerebrospinal fluid leakage, which are commonly observed. Considering that the overall complication rate after a typical lumbar laminectomy ranges from 2.5% to 7%, the postoperative complications observed in our study are considered acceptable [32].

### 4. Limitations

This is a retrospective, single-arm study without a control group. Therefore, it has inherent limitations owing to its study design. Also, the small study population limited the overall credibility of the study results. Furthermore, this is a preliminary result of a single center for only 1-year follow-up period. For a proper evaluation of LSPLS outcomes in treating lumbar spinal stenosis, further studies with better design and a large number of patients should be required.

## CONCLUSION

We found that LSPSL provides favorable clinical outcomes and an acceptable posterior bony structure restoration rate, making it a feasible treatment option for lumbar spinal stenosis. We believe that LSPSL is one of the promising minimally invasive decompressive surgery for treating lumbar spinal stenosis. Therefore, future research with a large number of patients and long-term follow-up is required to validate this promising procedure.

## NOTES

### Conflicts of Interest

The authors have nothing to disclose.

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# Translaminar Fully Endoscopic Discectomy for Lumbar Foraminal Disc Herniation: A Technical Note

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Lumbar disc herniations (LDHs) located in foraminal lesions are difficult to approach using the normal posterior approach while preserving the facet joints. The translaminar approach (TLA) of fully endoscopic spine surgery allows access to a foraminal lesion through a small fenestration on the isthmus of the vertebral lamina, thereby preventing facet joint destruction. TLA is particularly suitable for L5/S1 foraminal LDH cases where the transverse diameter of the foramen is anatomically long. From 2020 to 2022, TLA was performed in 17 patients with foraminal LDH (12 men and 5 women), with a mean age of 67 years. The operative levels were L3/4 in 1 case, L4/5 in 2 cases, and L5/S1 in 14 cases. The mean operative time was 72 minutes, and the mean blood loss was negligible in all patients. The mean postoperative hospital stay was 1.2 days, and no major complications occurred. The mean preoperative and postoperative Numerical Rating Scale scores for leg pain were 6.4 and 1.8, respectively, and the mean patient satisfaction score at 3 months after TLA was 7. In conclusion, TLA is a minimally invasive approach for foraminal LDH, with particular advantages for facet joint preservation.

**Key Words:** Full endoscopic spine surgery, Lumbar disc herniation, Discectomy, Translaminar approach, Minimally invasive

## INTRODUCTION

Foraminal and extraforaminal lumbar disc herniations (LDHs) have been reported to account for 6.5% to 12% of all LDH cases [1-3]. Compression of the spinal nerve and dorsal root ganglion may occur, causing severe pain that is often unresponsive to conservative management, requiring surgery [3].

Foraminal LDH are located ventral to the facet joints, making them difficult to approach using a normal posterior approach while preserving the facet joints, possibly resulting in postoperative instability. Although various modifications of standard open and microsurgical techniques have been described for foraminal LDH [1,2,4,5], endoscopically approaching the fo-

raminal lesions allows for facet joint preservation. There are 2 types of approaches: the transforaminal approach (TFA), which is accessed from approximately 8–12 cm lateral to the midline, and the translaminar approach (TLA), which is accessed by creating a small fenestration on the isthmus of the vertebral lamina. This article outlines the key points for foraminal LDH removal using full-endoscopic TLA.

## MATERIALS AND METHODS

### 1. Indication

TLA to access foraminal lesions, such as disc herniation and

foraminal stenosis, is particularly effective for foraminal LDH protruding from the medial part of the foramen at the L5/S1 level [6-8]. Because the transverse diameter of the L5/S1 foramen is anatomically long, it is relatively difficult. Furthermore, the iliac crest frequently disturbs disc puncture, which is an initial step in TFA. TFA for foraminal LDH is more challenging than for other vertebral levels.

Between 2020 and 2022, 896 full-endoscopic surgeries for LDH were performed at Iwai Orthopaedic Hospital. Among these, TLA was used in 17 patients with foraminal LDH.

The patients' background data, including age, sex, length of hospital stay, operation time, blood loss, surgical levels, Numerical Rating Scale (NRS) for leg pain at admission and discharge, and postoperative subjective satisfaction score (ranging from 1 [low satisfaction] to 10 [extreme satisfaction]), were retrospectively assessed at 3-month postsurgery.

## 2. Surgical Procedure

### 1) Anesthesia and skin marking

After induction of general anesthesia, the patients were placed in the prone position. Muscle relaxants were reversed and motor-evoked potential (MEP) monitoring was initiated. A fluoroscope centered across the operating table ensured appropriate positioning. An 8-mm skin incision was made 15–20 mm lateral to the midline. Although it can improve the intraoperative orientation, discography was not performed in all cases, as the puncture points differed.

### 2) Insertion of endoscope

The obturator was positioned on the lamina dorsal surface.

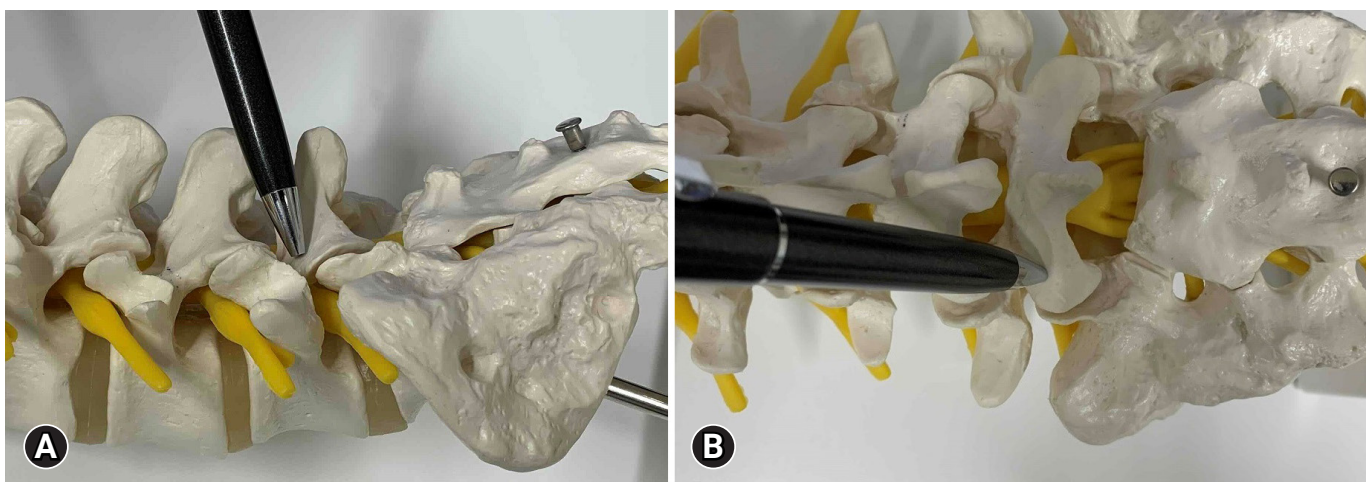
As fenestration is mainly performed in the isthmus of the lamina, the obturator was inserted parallel to the endplate at the level of the foramen while monitoring lateral fluoroscopy. A 7-mm diameter working sheath was placed at the deepest insertion site at a 30° angle (Figure 1A, B). Subsequently, an endoscope with a working channel diameter of 4.1 mm is introduced (RIWOspine GmbH, Knittlingen, Germany).

### 3) Surgical procedure (endoscopic manipulation)

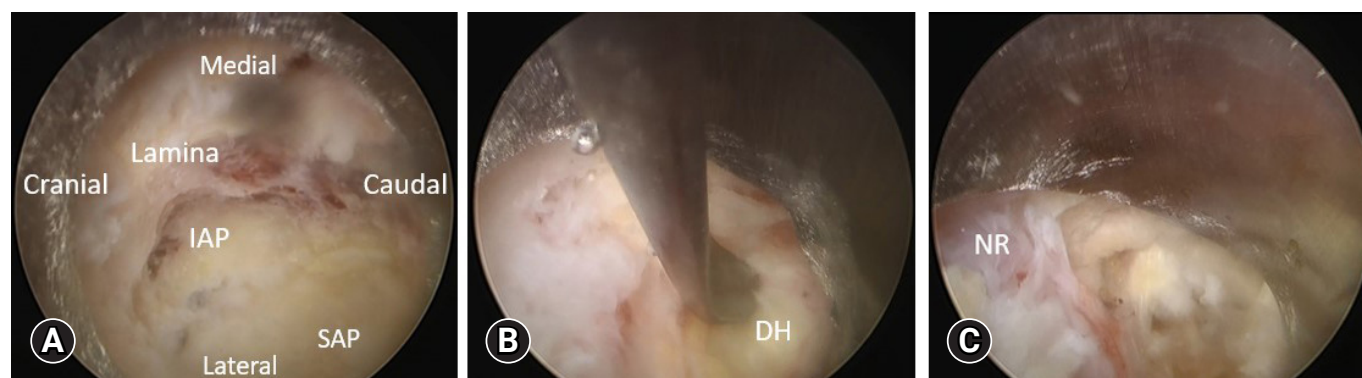
After inserting the endoscope, forceps and a bipolar radiofrequency electrode system (Elliquance, Baldwin, NY, USA) were used to expose the isthmus of the lamina. Instrument positioning was confirmed using a lateral fluoroscopic view. The lamina was thinned using a 3.5-mm diameter (NSK-Nakanishi Japan, Tokyo, Japan) diamond bar on a high-speed drill. The area of bone resection should be approximately 10 × 10 mm instead of focusing on a single deep point. Cases of severe degeneration may require drilling the tip of the inferior articular process of the rostral lamina. After exposing the inner cortical bone of the lamina, resection of the inner cortical bone began at the site covering the superior articular process (SAP) to provide guidance and ensure safe progression (Figure 2A). After SAP resection, the vertebral disc underneath was visible (Figure 2B) and could be subsequently removed.

### 4) Final checking point

After successfully performing the discectomy, the decompressed nerve root became visible (Figure 2C). Decompression of the nerve root may increase the MEP response in the corresponding nerve root region. No drains were placed and bedrest was not required 3-hour postsurgery. The patient was



**Figure 1.** The location and angle of the endoscope. Anteriorposterior (A) and lateral (B) views.



**Figure 2.** Intraoperative image of left L5/S1 fully endoscopic discectomy via the translaminar approach. (A) Exposure of the superior articular process (SAP) after removal of the inferior articular process (IAP). (B) Exposure of the disc herniation (DH) after removal of SAP. (C) Decompressed nerve root (NR) visible after removal of the DH.

discharged on the following day. Preoperative magnetic resonance imaging (Figure 3A, B) and postoperative computed tomography demonstrating the extent of bone removal in the left L5/S1 foraminal LDH (Figure 4A–C) are shown.

### 3. Ethics Statement

This study was approved by ethics committee of the Iwai Medical Foundation, and informed consent was obtained from the patients for publication of this study and any accompanying images.

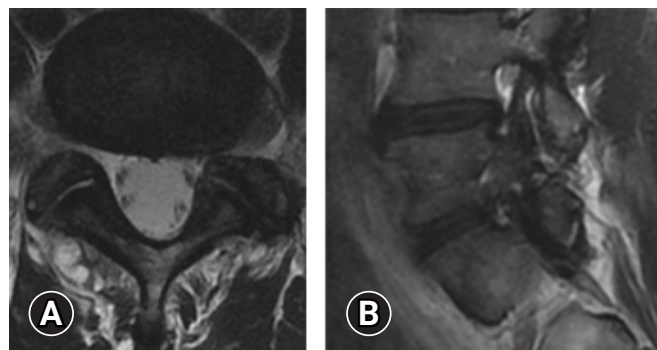
## RESULTS

Of the 17 patients, 12 were men and 5 were women (mean age, 67 years). The operative levels were L3/4 in 1 case, L4/5 in 2 cases, and L5/S1 in 14 cases. The mean operative time was 72 minutes; blood loss was negligible in all patients. The average postoperative stay was 1.2 days, and there were no major complications. The mean pre- and postoperative NRS for leg pain improved from 6.4 to 1.8. The mean patient satisfaction score was 7 (Table 1).

## DISCUSSION

Discectomy for foraminal LDH reportedly has a higher postoperative incidence of residual radicular pain and paresthesia than central LDH due to direct compression of the dorsal root ganglion [9].

Upward migrated LDH to the axilla of the exiting nerve has been termed the “hidden zone” by Macnab in 1971, and accounts for 10% of patients with extruded LDH [10]. Preservation



**Figure 3.** Preoperative magnetic resonance image showing left L5/S1 foraminal stenosis. (A) Sagittal view. (B) Axial view.

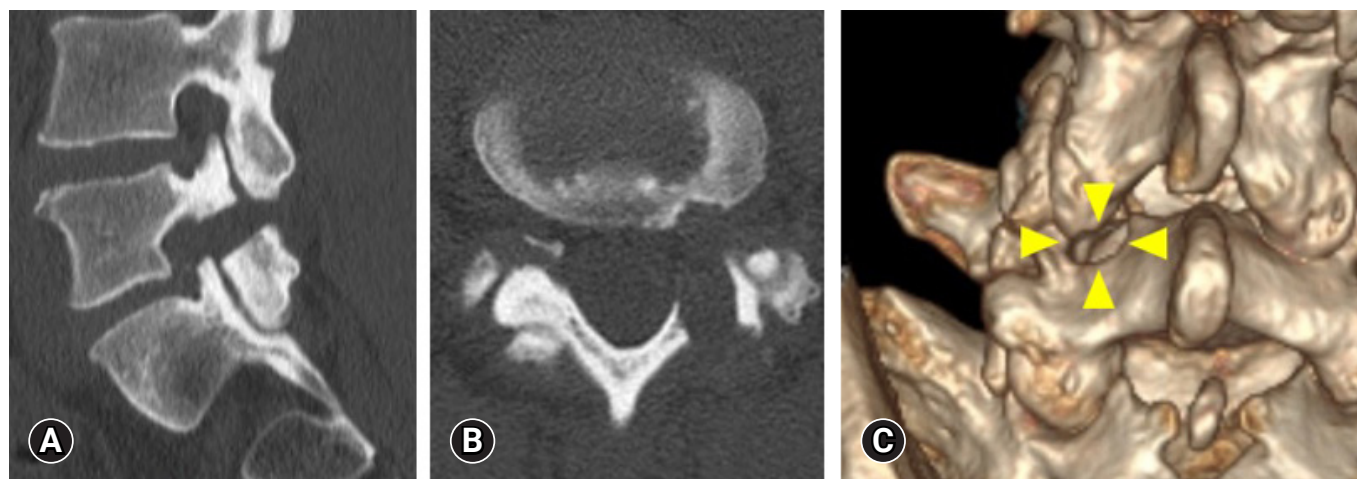
of the facet joints with the conventional posterior approach is challenging, and postoperative instability can be a concern.

The TLA was developed to approach the hidden zone directly from above by creating a window in the isthmus part of the lamina. Many reports exist using the transpars approach using the open technique by Di Lorenzo et al. [4] in 1998, as well as reports utilizing the caspase retractor, tubular retractor under the microscope, and endoscopic techniques [5,11]. Currently, an 8-mm full-endoscopic surgery is considered the least invasive technique [12–16].

The endoscope has a 25° angle at its tip, allowing for a wider osteotomy of the deeper layers compared to the superficial layers. This enables preservation of the medial and lateral lamina, thereby preventing iatrogenic spondylolisthesis.

The TFA for foraminal lesions is also effective [17]; however, accessing the medial side of the foramen at the L5/S1 level is challenging because of the iliac crest. Accessing the foramen in patients with degenerative narrowing of the L5 transverse





**Figure 4.** Postoperative computed tomography showing the range of bone removal. (A) Sagittal view. (B) Axial view. (C) Three-dimensional view. Arrowheads indicate the areas of removed bone.

**Table 1.** Summary of 17 cases

Case No.	Age (yr)	Sex	Level	Operation time (min)	Postoperative stay (day)	Preoperative NRS	Postoperative NRS	Satisfaction score
1	81	M	L4/5	71	1	8	1	8
2	85	M	L5/S1	58	1	6	3	10
3	63	M	L5/S1	88	1	8	5	4
4	56	M	L5/S1	80	1	3	0	8
5	49	M	L5/S1	68	1	5	3	10
6	73	M	L5/S1	74	1	6	0	7
7	60	M	L4/5	67	1	3	0	9
8	44	M	L5/S1	81	1	10	5	5
9	72	F	L5/S1	62	2	9	3	10
10	72	M	L5/S1	76	1	5	0	7
11	77	F	L5/S1	57	1	4	3	8
12	54	M	L5/S1	112	1	9	2	6
13	54	M	L5/S1	72	1	3	1	5
14	81	F	L3/4	56	1	9	2	4
15	76	M	L5/S1	61	1	7	2	8
16	70	F	L5/S1	83	2	9	0	8
17	72	M	L5/S1	59	2	5	2	2

NRS, Numerical Rating Scale.

process and sacral alar is also difficult. In such cases, the TLA is more suitable than the TFA.

TLA is also useful for accessing the hidden zone at L4/5 and higher; although, iatrogenic spondylolisthesis due to excessive bone resection is possible, as the width of the isthmus becomes narrower anatomically at higher lumbar levels.

The average age of the patients in this study was slightly higher and many had mild foraminal stenosis. TLA can also enlarge the corresponding foramen in cases of foraminal stenosis by drilling the SAP [6-8].

Extraforaminal lesions are unsuitable for use in TLA because they are inaccessible. The posterolateral approach, which is

accessed 5–8 cm lateral to the midline, is appropriate for extraforaminal pathologies. Therefore, an accurate preoperative diagnosis of the nerve root compression location using imaging and electrophysiological studies is crucial.

TLA is a minimally invasive approach to reach the foraminal lesion; however, it should only be performed after mastery of the usual endoscopic approach techniques, as the lack of anatomical landmarks is challenging for beginners in endoscopic surgery.

## CONCLUSION

Full-endoscopic TLA for foraminal LDH is not only a mini-



minimally invasive but also useful approach to preserve facet joint.

## NOTES

### Conflicts of Interest

The authors have nothing to disclose.

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# Nerve Root Herniation With Entrapment After Endoscopic Spine Decompression

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Incidental dural tears are common complications of endoscopic lumbar spine surgery. Postoperative nerve root herniation with entrapment is a rare consequence. We report our experience of postoperative nerve root herniation with an incidental dural tear as a cause of sudden sciatic pain. If a dural tear is not amenable to repair using an endoscopic method, open conversion with microscopic duroplasty should be considered as the initial approach given its prognosis. Additionally, if a patient suddenly develops unexplained sciatica after lumbar spine surgery, nerve root herniation with entrapment should be considered in the differential diagnosis.

**Key Words:** Laminectomy, Spinal nerve roots, Radiculopathy

## INTRODUCTION

Incidental dural tear is a common complication of a lumbar spine surgery. It has been reported that the incidence of dural tears is much higher in endoscopic procedures [1]. However, nerve root herniation with entrapment that causes severe radiating pain through incidental dural tear is a relatively rare phenomenon [2]. We report a rare case of nerve root herniation with entrapment as the cause of postoperative sciatica without showing any signs of cerebrospinal fluid (CSF) leakage after endoscopic lumbar spine surgery.

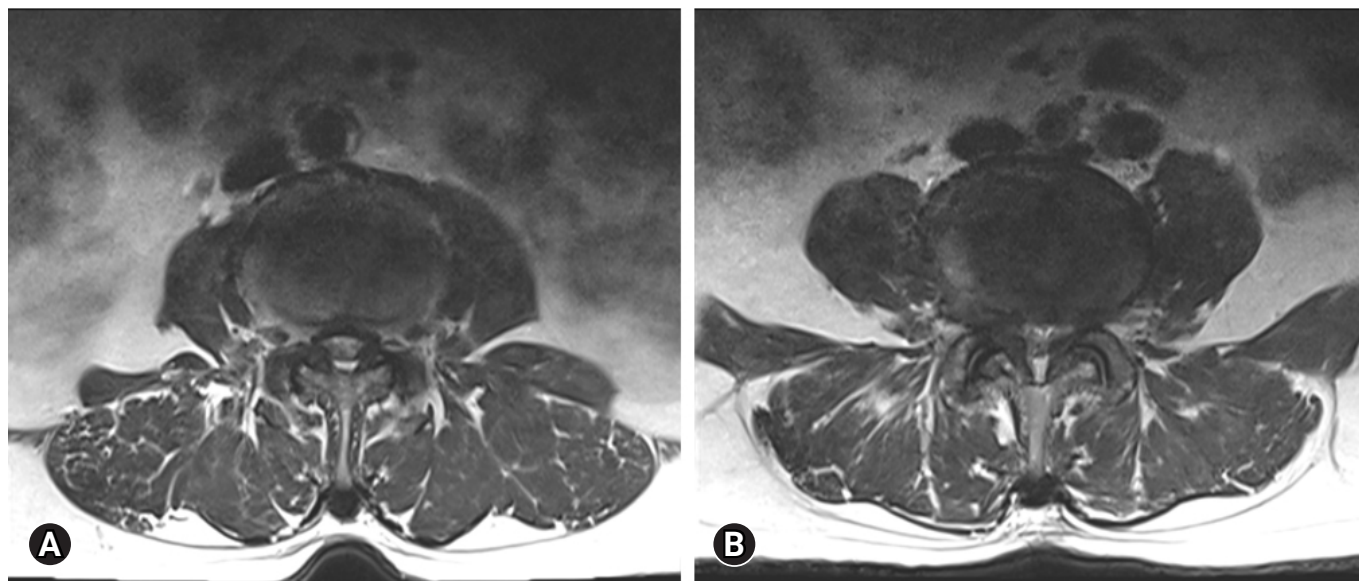
## CASE REPORT

A 75-year-old woman presented with neurogenic claudication, experiencing a maximum walking distance of approximately 500 m. Additionally, she reported radiating pain from the buttock region to the lateral thigh on the right side that had been present for the past 6 months. She had previously

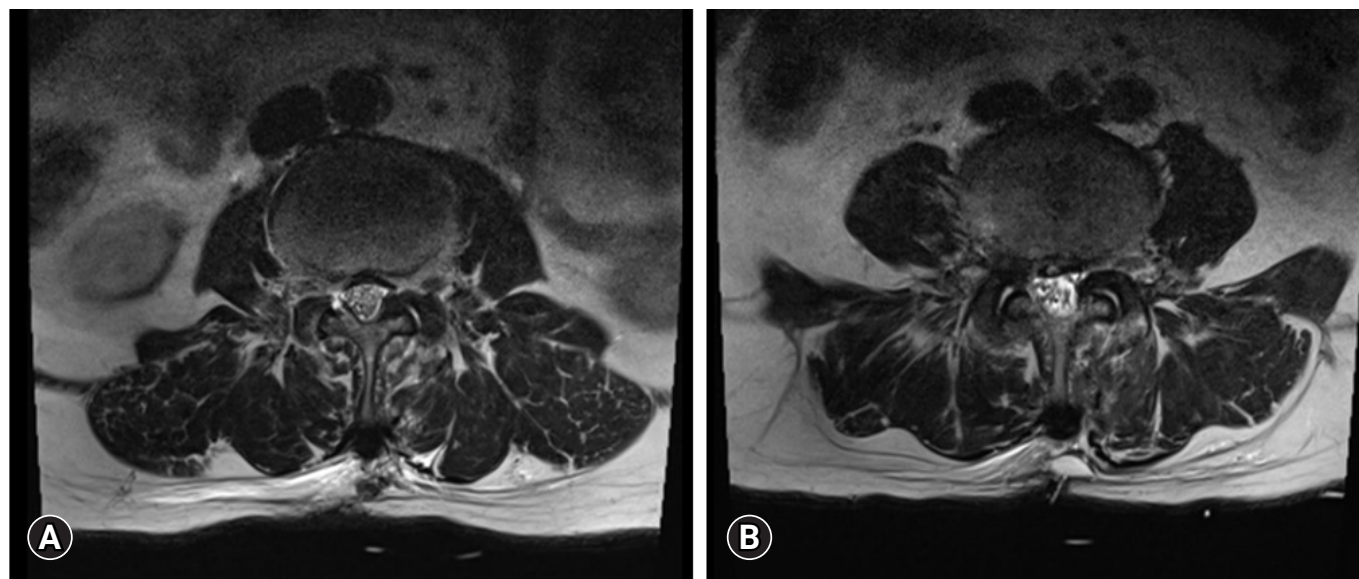
received several epidural blocks at private clinics but saw no improvement. Physical examination showed mild weakness in ankle dorsiflexion and knee extension. She had a medical history of hypertension and dyslipidemia and underwent microdiscectomy of the L5-S1 level on the right side 4 years ago. Magnetic resonance imaging (MRI) showed lumbar central stenosis at L3-4 and L4-5 levels with L5 lumbarization and stable degenerative spondylolisthesis (Figure 1).

The patient underwent an endoscopic unilateral laminectomy with bilateral decompression at L3-4 and L4-5 levels using a left-sided approach. The hypertrophied ligamentum flavum at each level was identified and removed. During the operative procedure, dural tearing or CSF leakage was not detected on endoscopic view. Postoperative lumbar MRI showed no evidence of CSF leakage (Figure 2). The patient showed improvement without neurological deficits after the operation. She was discharged in a tolerable state.

Seven days after discharge, she experienced a sudden onset of severe sciatica in her right lateral thigh. An MRI revealed



**Figure 1.** Axial magnetic resonance imaging taken preoperatively, demonstrating central canal stenosis with ligamentum flavum hypertrophy at L3–4 (A) and L4–5 (B).

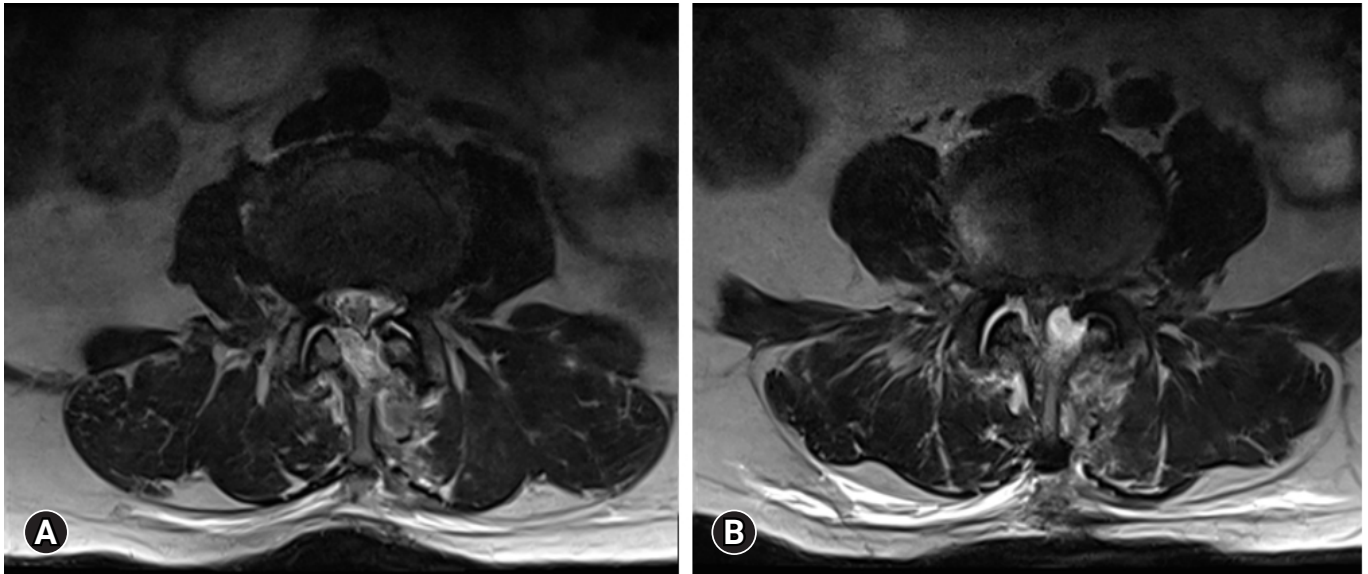


**Figure 2.** Axial magnetic resonance imaging taken postoperatively, showing a decompressed thecal sac without evidence of cerebrospinal fluid leakage at L3–4 (A) or L4–5 (B).

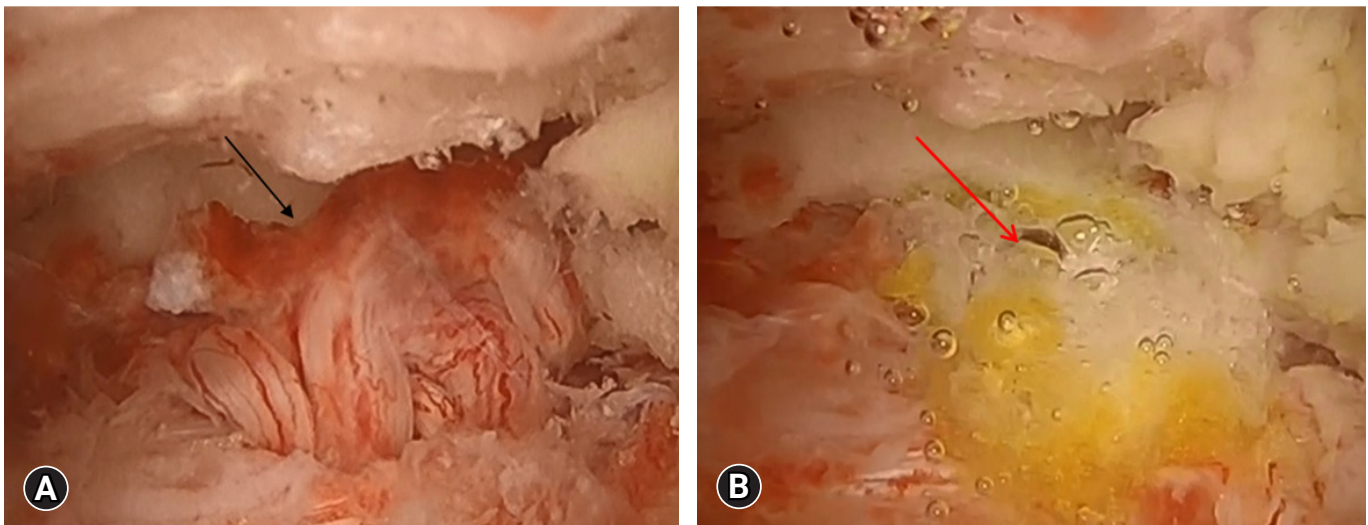
a moderate epidural fluid collection at L3–4 and L4–5 levels without evidence of an epidural hematoma (Figure 3). The pain was intractable and unresponsive to any painkillers. Thus, we decided to perform an operative site exploration using an endoscope. During the operation, a dorsal dura tear was observed along with nerve root entrapment at the L3–4 level. We then pushed the herniated nerve root into the thecal sac and patched the dura defect with a fibrin sealant patch (Tachosil,

Nycomed, Zurich, Switzerland) (Figure 4). Following the second operation, the patient reported a significant improvement in the preoperative right leg pain.

Fourteen days after the endoscopic exploration, the patient experienced a sudden onset of sciatic pain throughout her entire right leg. An MRI was performed, which showed recurrent epidural fluid collection at L3–4 and L4–5 levels (Figure 5). Initially, an epidural block was performed. However, it did not



**Figure 3.** Axial T2 magnetic resonance imaging, showing epidural fluid collection at both L3–4 (A) and L4–5 (B), suspicious for cerebrospinal fluid leakage.



**Figure 4.** Endoscopic view of the spinal canal. (A) Dura tear with nerve root herniation (black arrow). (B) Tachosil (Nycomed, Zurich, Switzerland) is inserted through the dural defect (red arrow).

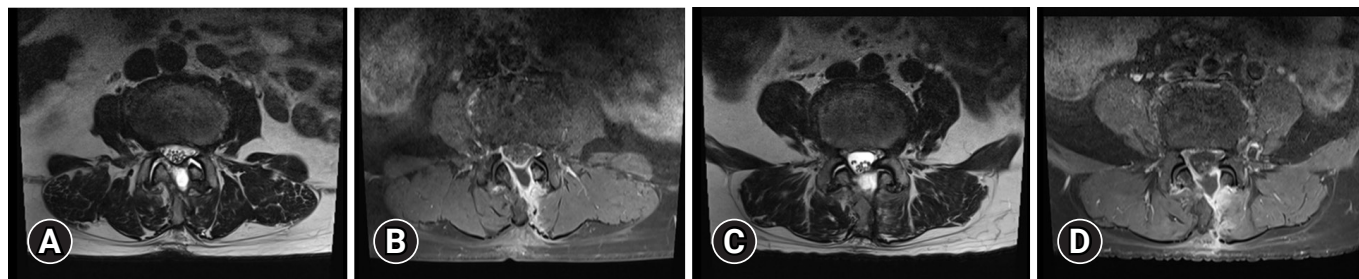
result in significant improvement. We suspected that nerve root herniation had recurred. Therefore, a microscopic exploration was necessary. The third operation involved an extended hemilaminectomy at L3. Since a consistent dura tear and nerve root herniation with entrapment were found at the L3–4 level, the entrapped nerve root was repositioned, and a duroplasty was performed via primary closure. Postoperatively, the patient's sciatica was immediately relieved. There was no recurrence during the 6-month follow-up period.

Written informed consent was obtained from the patient for publication of this case report and accompanying images.

## DISCUSSION

With rapid evolution of surgical techniques and materials, endoscopic spine surgery is already moving toward becoming the standard in the treatment of degenerative pathologies [3]. Since spinal dura includes nerves and CSF with 2 layers (in-





**Figure 5.** T2 axial (A) and T1 axial contrast-enhanced (B) magnetic resonance imaging at the level of L3–4, and T2 axial (C) and T1 contrast-enhanced axial (D) magnetic resonance imaging at the level of L4–5 showing epidural fluid collection suspicious for cerebrospinal fluid leakage. The nerve root herniation does not seem unclear in these images.

ner and outer membranes), it is prone to tear [4]. Especially when performing an endoscopic spine surgery, endoscopic repair of dura tear is challenging for spine surgeons because of its limited operative field [5]. Several articles have introduced management of dura tear using an autologous muscle graft or fibrin-sealed collagen sponge after endoscopic lumbar surgery including studies of Müller et al. [1] and Oertel and Burkhardt [6].

There are many reasons for recurrence of sciatic pain after a spine decompression surgery. Postoperative epidural hematoma and insufficient decompression are common reasons [7]. However, unrecognized incidental dural tear should be considered for its potential associated symptoms and complications [2]. In case of incidental dural tear during operation, many surgeons usually pay attention to symptoms for intracranial hypotension due to CSF leakage (i.e., postural headache, nausea, and so on). However, a less known complication of such a dural tear represents a postoperative nerve root herniation. In many cases described by several authors, the clinical course of nerve root herniation shows a temporary improvement after surgery and a sudden onset of intractable radiating pain. Popadic et al. [2] have reported a similar case with postoperative nerve root herniation.

When patients experience sudden recurrence of severe radiating pain after decompression surgery, physicians should consider postoperative nerve root herniation with entrapment regardless of the presence of dura tear, as well as postoperative hematoma or nerve compression. Whether dural tear requires surgical treatment during endoscopic spine surgery is still debatable.

Whether dural tear requires surgical treatment is still debatable. Park et al. [7] have reported that when intraoperative dural tearing occurs during endoscopic procedure, size estimation should be performed and dural defect less than 12 mm can be solved by application of fibrin sealant patch. However, dural

defect more than 12 mm should be solved with nonpenetrating titanium clip or primary suture. As we can see in our case, when large dural defect occurs, it is not feasible to manage the defect with an endoscopic method, with conversion to open-spine surgery being a better option.

## CONCLUSION

We report a complicated dural injury case that caused postoperative sciatica. When sudden sciatica recurs after endoscopic spine surgery, unrecognized incidental dural tear followed by postoperative nerve root herniation with entrapment should be considered as well as postoperative hematoma or nerve compression. In such case, open conversion with microscopic duroplasty should be considered first rather than endoscopic procedure considering prognosis.

## NOTES

### Conflicts of Interest

The authors have nothing to disclose.

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# Intraoperative Anteropulsion of an Interbody Fusion Cage During Minimally Invasive Transforaminal Lumbar Interbody Fusion: A Case Report

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Expandable cages are very commonly used during minimally invasive lumbar interbody fusion surgery for better restoration of sagittal alignment. We present a rare event of intraoperative expandable cage anteropulsion into the retroperitoneal space. To date, several cases of cage migration have been reported. However, ours is the first case of intraoperative anterior cage migration during minimally invasive lumbar fusion. Herein, we present a case of 70-year-old female planned for minimally invasive transforaminal lumbar interbody fusion (MIS TLIF) for grade II L5-S1 lytic spondylolisthesis. There was an unnoticed anterior longitudinal ligament rupture during the cage expansion manoeuvre. Cage dislodgment was noticed intraoperatively. This was managed by compression of the interbody site posteriorly and insertion of another snugly fitting bullet cage, followed by anterior retroperitoneal exploration in the same setting to retrieve the migrated cage. The patient's postoperative course was satisfactory. At a 1-year follow-up, patient was ambulatory and asymptomatic. Follow-up imaging showed bony fusion and no signs of implant failure. Expandable TLIF cages can cause iatrogenic release of the anterior longitudinal ligament during expansion. Surgeons must be aware of this rare complication, which can result in anterior cage migration.

**Key Words:** Lumbar vertebrae, Surgery, Spine, Spine pathology, Instrumentation

## INTRODUCTION

Transforaminal lumbar interbody fusion (TLIF), a posterolateral approach to lumbar fusion, was initially described in 1982 by Harms and Rollinger. It gained popularity in 1992 after work by Harms and Jerszenszky [1,2]. Open TLIF procedure carries the disadvantage of iatrogenic soft tissue injury. A novel surgical technique of minimal invasive TLIF (MIS TLIF) by use of serial tubular dilators and muscle retracting approach was introduced by Foley et al. [3] in early 2005 which has now become increasingly popular. Although rare, anterior cage

migration during TLIF can be catastrophic and life threatening with possibility of vascular and bowel injuries [4-6]. We present a case report of intraoperative anteropulsion of a cage into the retroperitoneum during MIS TLIF. To date, several cases of cage migration have been reported. However, this is the first case that reports intraoperative anterior cage migration during MIS TLIF.

## CASE REPORT

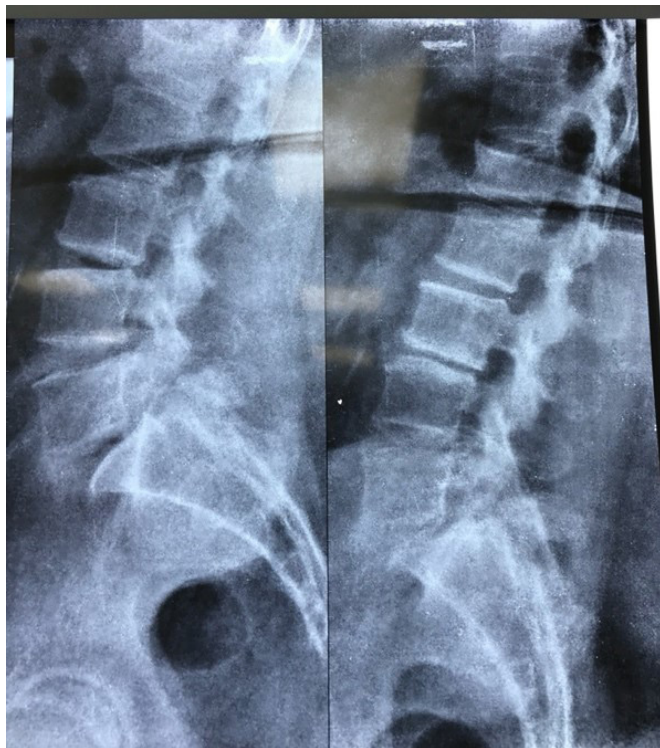
A 70-year-old female with body mass index of 40 was seen

at the spine clinic, with history of low back pain over one year with aggravation of symptoms, bilateral lower limb radiculopathy and neurogenic claudication for around 6 weeks. The onset of symptoms was insidious without any prior traumatic event. On examination, walking distance was less than 500 m with no neurological deficit. Reflexes and other general spine examination was found to be normal. She was advised magnetic resonance imaging (MRI) of the lumbosacral spine and dynamic lumbosacral x-rays which were suggestive of grade 2 mobile L5-S1 lytic spondylolisthesis (Figure 1). Patient had no other comorbidities except her obesity. Patient underwent MRI scans depicting findings as shown in Figure 2. Given the radiographic findings, surgical plan was MIS TLIF with expandable cage.

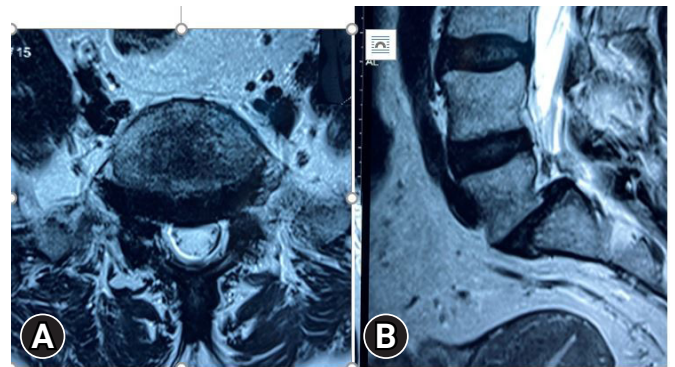
### 1. Surgery and Intraoperative Complication

Decompression and interbody fusion were performed with expandable Medtronic tube system. Unilateral facetectomy and discectomy was done after direct visualization and protection of traversing and exiting nerve roots. *Shavers of progressively increasing size were used for interbody site preparation and residual disc material was removed. Endplate preparation was*

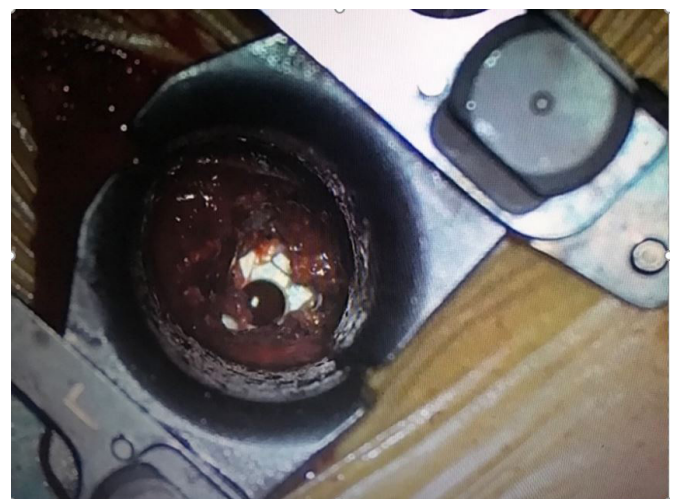
*done with help of straight and 30 degree bend curette as provided in the implant set. Intraoperatively, after end plate preparation, trial cage was inserted and checked on C arm. After appropriate selection of trial cage which was snugly fitting on both endplates, Wave-D expandable cage (Medtronic, Minneapolis, MN, USA) of 12 mm was inserted and further expanded to 14 mm after placement between L5-S1 vertebral bodies. Position of the cage after expansion was found to be appropriate. After removal of holder, bone graft was inserted into the expandable cage. The cage slipped from its position after graft insertion and this was noticed through the microscope. Intraoperatively, total slippage of the cage through the anterior margins of both L5-S1 vertebral bodies breaching the anterior longitudinal ligament (ALL) was identified, potentially risking major vessel and bowel. No attempts were made to remove the cage posteriorly considering potential devastating complications which may arise and it was left *in situ* (Figure 3).*



**Figure 1.** Dynamic x-ray film of lumbosacral (LS spine) suggestive of mobile grade II lytic spondylolisthesis at L5-S1. Extension view (A) and flexion view (B).



**Figure 2.** Axial (A) and sagittal (B) magnetic resonance images.



**Figure 3.** Microscopic views of anterior slippage of Medtronic Wave-D expandable PEEK cage after graft insertion.



## 2. Surgical Management

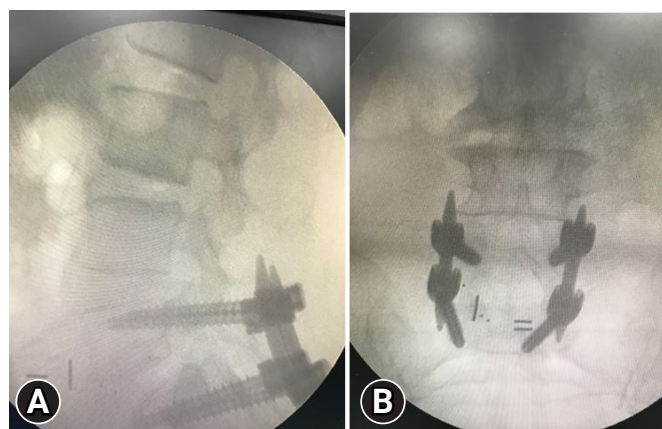
After notifying anaesthesia team, vitals were noted stable, and an on call vascular access surgeon was informed. Pedicular screws of size 6.5 mm×40 mm were inserted at L5–S1 level and fixed with rods. Meanwhile decision was taken to insert another nonexpandable bullet cage measuring 12 mm packed with bone graft. The interbody site was compressed first to reduce the anterior defect and then a bullet cage of size 12 mm was inserted. It was positioned off centre and fitted snugly to prevent slippage through an apparent central defect in ALL (Figure 4). Wound was closed in layers and intraoperative consent was taken from relatives after explaining the complication. The patient was positioned supine and the migrated expandable cage was approached through anterior retroperitoneal approach which was found below bifurcation of abdominal aorta. On direct visualization, there was no visceral injury. The dislodged cage was then removed and wound was closed in layers (Figure 5). Postoperatively, patient was haemodynamically stable. At 1 year of follow-up, patient was ambulatory and asymptomatic. Follow-up imaging showed bony fusion and no signs of implant failure.

## 3. Ethics Statement

A valid informed consent of patient was taken for publication of case report.

## DISCUSSION

With changing demographics, prevalence of diseases related



**Figure 4.** Fluoroscopy lumbar spine lateral view (A) and anteroposterior view (B) showing posterior fixation with bullet cage while leaving anteropulsed cage *in situ*.

to aging has increased. TLIF offers circumferential arthrodesis of spine via single stage posterior approach. The advent of microscopic surgeries has allowed TLIF procedure to become minimally invasive i.e., MIS TLIF; which offers added advantages of lesser tissue trauma, less blood loss, reduced infection rates and early mobilization. Drift towards minimally invasive techniques of interbody fusion has increased challenges dealing with complications. Besides neural injury, infection, dural injury and screw malposition, TLIF carries risk of cage migration. Cage migration can be classified as anterior, posterior or sagittal, depending upon the direction [7]. Anterior cage migration has catastrophic complications due to visceral injury [5,6,8,9].

There are no fixed guidelines for retrieval of anteriorly migrated cages due to paucity of literature. L4–5 [8] and L5–S1 [10] are the most common sites of anterior TLIF cage migration. In our case, L5–S1 was the site of cage migration. Retroperitoneal migration of cage usually occurs due to over preparation of disc space, uncontrolled hammering of cage during insertion without fluoroscopy, inappropriate position of cage, osteoporosis and ALL rupture [4,8]. Severe obesity or decreased load bearing capacity has been documented to increased risk of cage migration [11].



**Figure 5.** Image of retrieved anteropulsed cage through anterior retroperitoneal approach.



Wong et al. [12] found a 0.97% of cage migration in their MIS TLIF series of 512 patients. In selected cases where cage had migrated anteriorly and vitals remained stable, the surgery was completed leaving the cage/graft in place [4]. Although in other cases immediate removal of cage/graft was done to prevent impending complication due to major vessel compression [13]. Iatrogenic perforation of ALL during discectomy has been reported in the literature with collateral damage to bowel and left common iliac artery and vein [14,15].

In our case, we used wave-D expandable cage to attain additional lordosis which also has the provision of inserting bone graft after cage expansion to accommodate a large graft size. While inserting bone graft inside the expanded space using a funnel, dislodgment and anterior migration of the cage was noticed. Intraoperatively a central breach in the ALL was documented which is thought to be happened during cage expansion manoeuvre. Our case has come to show that while improving lordosis through an expandable cage from a posterior approach, iatrogenic ALL breach can be an impending complication especially in old fragile patient and with aggressive surgical manoeuvres. *Care should be taken that bigger size shavers and overzealous use of curettes to remove the endplate might damage the subchondral bone. This damage to bone may cause complications of implant subsidence. Although in our case, some manoeuvres performed during endplate preparation might be contributing factors of ALL damage, it was only during cage expansion that the ALL gave away and cage slipped anteriorly.*

Unlike previously reported cases of anterior cage migration, we inserted snugly fitting nonexpandable bullet cage of 12-mm size pre-packed with bone graft. This was done only after compressing pedicle screw over rods so as to minimise the anterior ALL opening. Most commonly, anterior transperitoneal or lateral retroperitoneal approaches are recommended for cage extraction [16]. We took retroperitoneal approach with the help of vascular access surgeon and retrieved the migrated cage. The rationale behind inserting another cage was to obtain stable construct with anterior column support.

## CONCLUSION

In summary, surgeons must be aware of intraoperative anterior cage migration due to iatrogenic rupture of ALL while using expandable interbody cages. The exact incidence of such events is rare and due to scarcity of literature, comprehensive management guidelines are lacking.

## NOTES

### Conflicts of Interest

The authors have nothing to disclose.

### Funding/Support

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- 5) A list of key words, with a minimum of two items and maximum of six items, should be included at the end of the abstract.
- 6) The selection of Key Words should be based on Medical Subject Heading (MeSH) of Index Medicus and the web site (<http://www.nlm.nih.gov/mesh/MBrowser.html>).

### 4. Introduction

- 1) The introduction should address the purpose of the article concisely, and include background reports mainly relevant to the purpose of the paper. Detailed review of the literature should be addressed in the discussion section.

### 5. Materials and Methods

- 1) The article should record research plans, objective, and

methods in order, as well as the data analysis strategies and control of bias in the study. Enough details should be furnished for the reader to understand the method(s) without reference to another work in the study described.

- 2) When reporting experiments with human subjects, the authors must document the approval received from the local Institutional Review Board. When reporting experiments with animal subjects, the authors should indicate whether the handling of the animals was supervised by the research board of the affiliated institution or such. Approved number of IRB must be noted.
- 3) Photographs disclosing patients must be accompanied by a signed release form from the patient or family permitting publication.
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- 1) The authors should logically describe their results of observations and analyses performed using methodology given in the previous section and provide actual data.
- 2) For biometric measurements in which considerable amount of stochastic variation exists, a statistical evaluation is mandatory. The results must be solely from the findings of the current study and not refer to any previous reports.
- 3) While an effort should be made to avoid overlapping descriptions by Tables and by main text, important trends and points in the Table should be described in the text.

## 7. Discussion

- 1) Discussions about the findings of the research and interpretations in relation to other studies are made. It is necessary to emphasize the new and critical findings of the study, not to repeat the results of the study presented in the previous sections. The meaning and limitation of observed facts should be described, and the conclusion should be related to the objective of the study only when it is supported by the results of the research.

## 8. Conclusion

- 1) The conclusion section should include a concise statement of the major findings of the study in accordance with the study purpose.

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### <Journal>

1. Choi S, Lim WJ, Lee MK, Ryu KS. Lumbar interbody fusion using low-dose of recombinant human bone morphogenetic protein-2 (rh-BMP2): minimum 1-year follow-up results at a single institute. J Minim Invasive Spine Surg Tech 2021;6:2-8

### <Book>

1. Conover WJ. Practical Nonparametric Statistics, 2nd ed. New York : Jon Wiley & Sons, 1971, pp216-8

### <Chapter in a book>

1. Ojemann RG. Surgical management of bacterial intracranial aneurysms. In: Schmideck HH, Sweet HH (eds). Operative Neurosurgical Techniques: Indications, Methods and Results, 2nd ed. Orlando : Grune & Stratton, 1988, Vol 2, pp997-1001

### <Internet source>

1. Food and Drug Administration (FDA). Devices@FDA [Internet]. Silver Spring, MD: FDA; cited 2010 Jul 21. Available from: <http://www.accessdata.fda.gov/scripts/cdrh/device-satfda/index.cfm?pmanumber=P040006>.

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