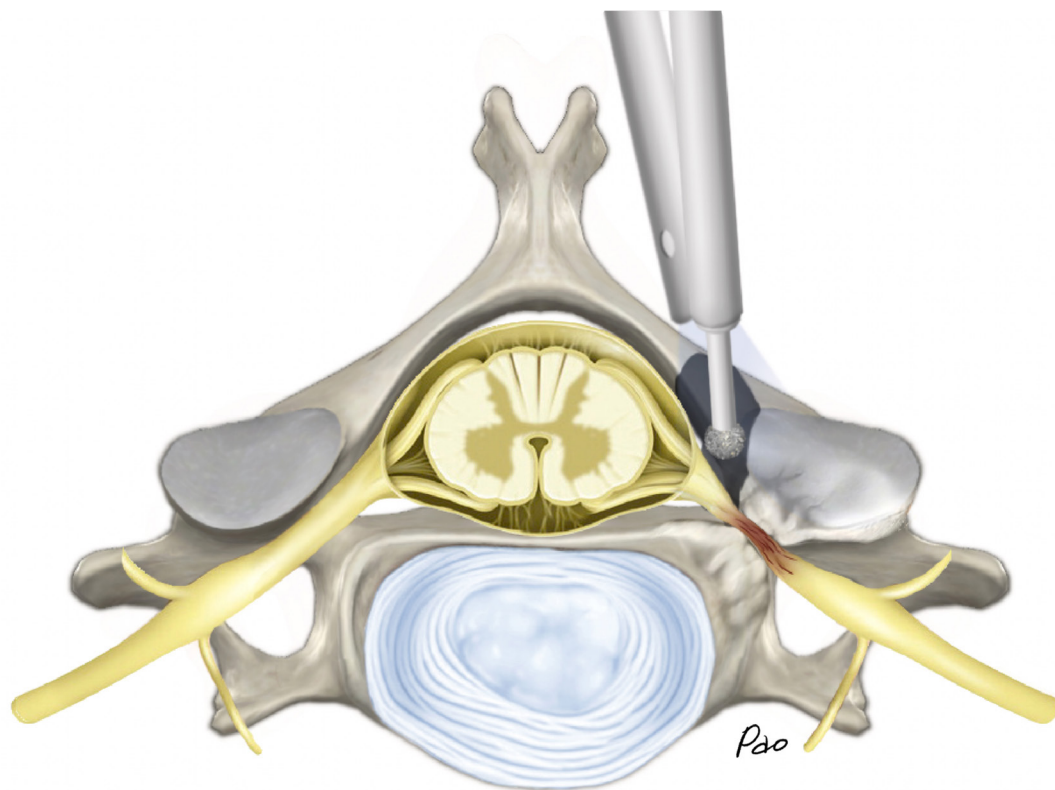


# JMISST

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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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# Maximal Benefit Zone of Endoscopic Spine Surgery in the Cervical and Thoracic Spine: Rationale of Endoscopic Spine Surgery in the Cervical-thoracic Region

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Complex anatomy, difficult access, and low tolerance of cord manipulation in the cervical and thoracic spine are some of the most challenging aspects of spine surgery. Open cervical and thoracic spinal surgery incurs substantial morbidity, with significant postoperative pain, blood loss, and risk of infection in open cervical and thoracic wounds. With the evolution of endoscopic surgical techniques and increasing familiarity with how to handle endoscopic equipment, the indications of endoscopic spine surgery have expanded to include cervical and thoracic spinal decompression in the surgical armamentarium for treating cervical and thoracic spinal pathologies to provide the maximal benefit zone of endoscopic spine surgery.

**Key Words:** Minimally Invasive Spine Surgery, Endoscopic Spine Surgery, Cervical Vertebrae, Thoracic Vertebrae, Cervical spine

## INTRODUCTION

Endoscopic Spine Surgery (ESS) has undergone rapid development in the last 20 years and has now broadened its spinal surgical indications which traditionally can only be performed with open surgeries [1]. Endoscopic spine surgery provides maximal benefit in cervical-thoracic region as this region is particularly vulnerable to postoperative morbidities [2]. The early postoperative positive effect of endoscopic spine surgery is it minimizes pain, hence patient can have optimal postoperative ventilation; it avoids the use of chest tube and reduces the usage of intensive care unit and high dependency; its potential benefit of motion preservation and its plausible future as an ambulatory cervical-thoracic procedure should be evaluated.

In this editorial we discuss the rationale of minimally invasive spinal procedure for cervical-thoracic region and its potential benefits to the patients (Figure 1).

## MINIMIZE PERIOPERATIVE PAIN IN POSTERIOR SPINAL APPROACH

One of limitation in posterior cervical-thoracic spinal surgery is significant postoperative neck and upper back pain due to stripping of paraspinal muscle in posterior approach [3]. Several articles had demonstrated good postoperative pain score and neck disability index after cervical-thoracic endoscopic spine surgery [4-6]. This is important to patients as postoperative neck pain is a significant limiting factor to early return to work.

**Sub-title: A minimally invasive approach to the cervical-thoracic spine**

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**Figure 1.** Editorial team for *Journal of Minimally Invasive Spine Surgery and Technique: A Minimally Invasive Approach to the Cervical-Thoracic Spine*.

## AVOIDANCE OF MORBIDITY OF ANTERIOR CERVICAL-THORACIC APPROACH

In lower cervical and thoracic spine, anterior approach to the thoracic spine through the chest cavity can lead to significant postoperative pain and ventilation issues [7]. ESS application in thoracic region may decrease such complications [8]. The risk of catastrophic vascular injury in anterior thoracic approach and the risk of pleura and lung injury in thoracic anterior approaches limits access to anterior spinal column in thoracic spine. Rib is often harvested to gain access to the anterior thoracic spine which leads to postoperative chest pain and potential ventilation issues. A posterolateral and transforaminal endoscopic thoracic discectomy surgeries which approach the thoracic anterior column from the posterolateral aspect of spine allows access to anterior spinal column without such morbidities. Transforaminal endoscopic thoracic discectomy procedures can be performed with local anesthesia [9], this decreases the need for respiratory support equipment used for

endotracheal intubation for general anesthesia.

## PLAUSIBLE CONCEPT OF AMBULATORY CERVICAL AND THORACIC SPINAL PROCEDURE

A single 1 cm incision in approach and avoidance of pleura related complication. A successful completion of transforaminal endoscopic thoracic discectomy under local anesthesia has the potential of being an ambulatory procedure [2].

## MOTION PRESERVATION IN CERVICAL AND THORACIC ENDOSCOPIC SPINE SURGERY

We had highlighted cervical-thoracic endoscopic surgery in treatment of degenerative pathologies in cervical and thoracic spine decreases in perioperative morbidities of these high risk surgeries [8,10,11]. The long term benefit of motion preservation in ESS in cervical-thoracic region is arguably the key factor for the pursuance of such procedures among spine surgeons. Anterior Endoscopic Cervical Discectomy [12] and Posterior Endoscopic Cervical Discectomy [13,14] can avoid anterior cervical discectomy and fusion or disc replacement. The patients who underwent ESS treatment can have motion preservation without implants. This is an attractive proposition to many patients.

## LONG TERM EVALUATION OF EFFECT OF CERVICAL-THORACIC ENDOSCOPIC SPINAL DECOMPRESSION REQUIRES MORE ACADEMIC STUDIES

As an academic community, we work together to evaluate the long term outcomes of these new endoscopic expansion of indications to assess benefits of this branch of sub specialization of spine surgery [15,16]. The learning curve in cervical-thoracic endoscopic spine surgery is steep and is a demanding procedure, we suggest surgeons who embark on these surgeries to be proficient in lumbar spinal surgeries first [2,17].

## MAXIMAL BENEFIT ZONE OF ENDOSCOPIC SPINE SURGERY IN CERVICAL-THORACIC REGION

The benefit zone of minimally invasive surgery is wider in more complex anatomical region and challenging surgical

procedures [18]. Although traditional open surgeries in cervical-thoracic region has good clinical outcomes, these surgeries have inherent postoperative morbidity and risks. Endoscopic spine surgery can potentially address these gaps by being direct to its target pathology and minimizing the soft tissue trauma, bypassing the difficult anatomy and providing an alternative route to cervical-thoracic region [15].

## CONCLUSION

The steep learning curve of cervical-thoracic endoscopic spine surgery is worth the challenge in view of significant perioperative and long term benefit of these procedures compared to traditional open procedures. There is potential for cervical-thoracic spinal endoscopy to be the minimally invasive procedure of choice in providing the maximal benefit zone to patients who require surgery in this complex surgical anatomical region.

## NOTES

### Ethical statements

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the Nanoori Hospital's Ethics Committee and the National Research Committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Consent from patients: All patients had given their informed consent for photographs, videos and images for publication.

Informed consent: Informed consent was obtained from all individual participants included in the study.

### Conflicts of interest

Hyeun Sung Kim and Pang Hung Wu are the Editor-in-Chief and Editorial Board of the Journal of Minimally Invasive Spine Surgery and Technique and were not involved in the review process of this article. All authors have no other potential conflicts of interest to declare relevant to this article.

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# The Growing Popularity of MISS: A Focus on Endoscopic Surgery for the Cervical and Thoracic Spine

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This editorial article explores advances in the field of spinal surgery, focusing on minimally invasive spinal surgery (MISS) and its applications in treating cervical and thoracic spine conditions. MISS has gained popularity due to its reduced pain, minimal scarring, and shorter recovery times compared to traditional open surgery. Endoscopic surgery, the core of many MISS procedures, offers several advantages, such as reduced blood loss, minimal tissue damage, shorter hospital stays, and enhanced visualization. However, it is important to emphasize the need for sufficient experience in endoscopic surgery and the adoption of more delicate techniques when addressing cervical and thoracic spine disorders, as more serious complications can occur in these regions than in the lumbar spine. Various endoscopic techniques, including anterior cervical discectomy, posterior cervical foraminotomy, thoracic discectomy, and thoracic decompression, have been successfully employed to treat cervical and thoracic spine disorders. As the field of spinal surgery continues to advance, the use of endoscopic techniques in MISS is expected to become more widespread, benefiting patients and contributing to a more efficient and cost-effective healthcare system.

**Key Words:** Minimal invasive spinal surgery, Endoscopic surgery, Cervical spine, Thoracic spine

## INTRODUCTION

The field of spinal surgery has seen significant advancements in recent years, primarily due to the rapid development of minimally invasive techniques. Among these, Minimal Invasive Spinal Surgery (MISS) has gained particular attention for its ability to treat patients with cervical and thoracic spine conditions with reduced pain, minimal scarring, and shorter recovery times [1-3]. This editorial article aims to provide an overview of MISS in the context of cervical and thoracic spine surgery, with a focus on endoscopic techniques as the cornerstone of these procedures. It is important to note that endoscopic cervical and thoracic spinal surgery requires sufficient experience in endoscopic surgery through lumbar surgery, and complications can

occur much more seriously than in the lumbar region, necessitating more delicate techniques [4,5].

## 1. The Need for MISS in Cervical and Thoracic Spine Surgery

Cervical and thoracic spine disorders can have a profound impact on an individual's quality of life, causing pain, disability, and limitations in daily activities. Traditional open spinal surgery can address these issues but often comes with a host of complications, including significant blood loss, muscle damage, and prolonged hospital stays [6-8]. As a result, the demand for MISS has grown exponentially as a more patient-friendlier alternative that can achieve similar, if not better, outcomes with

fewer risks and shorter recovery periods.

## 2. Endoscopic Surgery: The Core of MISS

Endoscopic spinal surgery, which utilizes an endoscope to access the spine through small incisions, is at the heart of many MISS procedures. The endoscope enables surgeons to visualize the surgical site without the need for large incisions, minimizing tissue damage and reducing postoperative pain [6-8].

There are several key advantages to endoscopic spinal surgery when compared to traditional open surgery, which contribute to the growing popularity of MISS in the treatment of cervical and thoracic spine disorders. However, it is essential to emphasize the need for sufficient experience in endoscopic surgery and the understanding that complications in the cervical and thoracic regions can be more severe than in the lumbar region [4,5].

### 1) Reduced Blood Loss and Pain

With the use of an endoscope, smaller incisions are required, leading to significantly less blood loss and postoperative pain. This not only makes the surgery itself more manageable for the patient but also leads to a faster recovery and reduced reliance on pain medications.

### 2) Minimal Tissue Damage

Open spinal surgery often involves the detachment of muscles and other soft tissues, resulting in increased postoperative pain and longer recovery times. Endoscopic surgery, on the other hand, preserves these tissues by creating a small, direct pathway to the spine. This results in less muscle and tissue damage, leading to a more rapid recovery.

### 3) Shorter Hospital Stays

Thanks to the minimal invasiveness of endoscopic spinal surgery, patients typically experience shorter hospital stays and a quicker return to normal activities. This not only benefits the patients but also reduces healthcare costs and hospital resource utilization.

### 4) Enhanced Visualization

The endoscope's camera allows for better visualization of the surgical site, providing real-time feedback to the surgeon.

This enhanced view enables more precise surgical techniques and increases the likelihood of a successful outcome. Again, it is crucial to emphasize that more delicate techniques are required when performing endoscopic surgery in the cervical and thoracic regions due to the potential for more serious complications.

## 3. Endoscopic Techniques for Cervical and Thoracic Spine Surgery

There are several endoscopic techniques that can be applied to MISS procedures for cervical and thoracic spine disorders.

Some of these techniques include:

### 1) Anterior Cervical Discectomy (ACD)

This endoscopic procedure is used to treat conditions such as cervical herniated discs. It involves the removal of the damaged disc through a small incision made in the front of the neck. While fusion of adjacent vertebrae can be performed in some cases to stabilize the spine, it is less common in endoscopic procedures due to the minimal invasiveness and the desire to preserve mobility [9,10].

### 2) Posterior Cervical Foraminotomy

This minimally invasive technique is employed to treat nerve compression caused by bone spurs or herniated discs in the cervical spine. The endoscope is used to access the affected area and remove the offending structures, relieving pressure on the nerves and reducing pain [11-13].

### 3) Thoracic Discectomy

This endoscopic procedure is used to treat herniated discs in the thoracic spine. The damaged disc is removed through a small incision, and the adjacent vertebrae may be fused if necessary to provide stability [14-16].

### 4) Thoracic Decompression

In cases of thoracic spinal stenosis due to ossification of ligamentum flavum (OLF) or bony spurs, endoscopic thoracic decompression can be performed to remove ligament and bony structures causing nerve compression. This technique can relieve pain and improve mobility without the need for fusion [17].

## CONCLUSION

Minimal Invasive Spinal Surgery (MISS) has emerged as a powerful tool in the treatment of cervical and thoracic spine disorders. Endoscopic surgery, as the core of many MISS procedures, offers numerous advantages over traditional open surgery, including reduced blood loss, minimal tissue damage, shorter hospital stays, and lower risks of complications. As a result, patients can experience improved outcomes with faster recovery times and a quicker return to their daily activities.

As the field of spinal surgery continues to advance, it is likely that the use of endoscopic techniques in MISS will become even more widespread. This will not only benefit patients suffering from cervical and thoracic spine conditions but also contribute to a more efficient and cost-effective healthcare system. The future of spinal surgery lies in embracing these minimally invasive techniques, and endoscopic surgery is undoubtedly leading the charge. However, surgeons must recognize the importance of gaining sufficient experience in endoscopic surgery and adopting more delicate techniques when addressing cervical and thoracic spine disorders to minimize the risk of serious complications.

## CONFLICT OF INTEREST

### Ethical statements

Not applicable.

### Conflict of interest

No potential conflict of interest relevant to this article.

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# Prevalence of Cervical and Thoracic Spinal Disease: A Systematic Review

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**Objective:** This study aimed to comprehensively assess the prevalence and distribution of degenerative cervical and thoracic diseases with compression of the spinal cord, such as disc herniation (TDH) or hypertrophied ligamentum flavum causing stenosis, by reviewing the literature.

**Methods:** We searched PubMed/MEDLINE to identify articles on the prevalence of degenerative diseases with compression of the spinal cord in the cervical and thoracic spine. The levels of evidence were classified according to the NASS 2005 method. We selected articles containing information on the prevalence of degenerative cervical and thoracic diseases.

**Results:** We identified 358 articles. Thirty-eight met our criteria, with evidence ranging from levels I to V. The prevalence of asymptomatic spinal cord compression lesions was found to be relatively high in elderly people with underlying conditions. Non-traumatic spinal cord injuries are caused by various degenerative diseases involving spinal cord compression, such as cervical myelopathy, ossification of the posterior longitudinal ligament, and ossification of the ligamentum flavum, and are observed in more than 50% of patients with lesions in Japan and the United States, more than 30% in Europe, and more than 20% in Australia. Regarding thoracic lesions, a prevalence of 5% to 10% has been reported for various spinal cord compression lesions such as herniated disc, ossification of the posterior longitudinal ligament, and ossification of the ligamentum flavum.

**Conclusion:** Spinal cord compressive lesions appear not to be rare in the cervical and thoracic spine. The radiographic findings of various stenotic lesions must be well understood and correlated with clinical symptoms before treatment decisions.

**Key Words:** Prevalence, Cervical spinal stenosis, Myelopathy, ossification of posterior longitudinal ligament, lesional spinal cord compression

## INTRODUCTION

An increase in the elderly population worldwide has led to an increase in spinal degenerative diseases and spinal surgery. Most of the surgeries are performed in the lumbar region, but recently, degenerative changes in the cervical and thoracic spine are increasing [1]. Additionally, to avoid unexpected neurological deterioration due to the coexistence of upper spinal

compression lesions, it is essential for surgeons to be aware of the prevalence and distribution of lesions in lumbar degenerative diseases.

In addition to the lumbar region, stenosis can occur in the cervical and thoracic regions, and can occur simultaneously. However, the literature on predictive radiologic findings of cervical stenosis related to thoracic stenosis is very scarce. The radiographic features of symptomatic cervical and thoracic ste-

nosis are clearly more important than those of asymptomatic stenosis.

However, unlike symptomatic cervical and thoracic stenosis, there is no clinical reason to undergo radiographic examination for asymptomatic stenosis. However, severe radiographic stenosis can be present without symptoms [2,3]. In most cases, these “silent” stenosis do not cause clinical sequelae.

However, there have been cases of paralysis of spinal origin after anesthesia or sleep in patients with asymptomatic spinal stenosis [4,5].

Ossification of the posterior longitudinal ligament (OPLL) and yellow ligament (OLF), which occur more frequently in the cervical and thoracic spine than in the lumbar spine, are characterized by replacement of the posterior longitudinal ligament and yellow ligament by ectopic new bone formation, respectively [6,7].

OPLL often causes a narrow spinal canal and has been recognized as one of the causes of cervical myelopathy and/or radiculopathy [6,8]. OLF is also well known as one of the causes of thoracic myelopathy by compressing the spinal cord from the posterolateral side [7].

In addition, disc herniation in the cervical and thoracic region accompanies various neurologic symptoms of radiculopathy and myelopathy depending on the location and degree of herniation.

This study aims to review the literature on the prevalence of symptomatic degenerative diseases that cause neurological symptoms in the cervical and thoracic spine, and to report the analysis as a systematic review and narrative analysis.

## MATERIALS AND METHODS

We used the Preferred Reporting Items as templates for our systematic review. The review process started with a search of the PubMed database to identify articles on prevalence of degenerative cervical and thoracic spinal disease. An independent reviewer assessed all articles and references and agreed on which articles should be included. To prevent selection bias during the review, abstracts from the search were numbered and pasted into a document after deleting the publication journal, author, and institution. We used the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines as templates for this systematic review. These guidelines are an evidence-based minimum set of items aimed at helping authors improve their reporting of systematic reviews and meta-analyses. The review process started with a search of the PubMed and Cochrane databases to identify articles on

prevalence of degenerative cervical and thoracic spinal disease protocol. A reviewer assessed all articles and references and agreed on which articles should be included. To prevent selection bias during the review, abstracts from the search were numbered and pasted into a document after deleting the publication journal, author, and institution. The initial search included the keywords “prevalence of cervical spinal disease” and “prevalence of thoracic spinal disease” which returned 358 results.

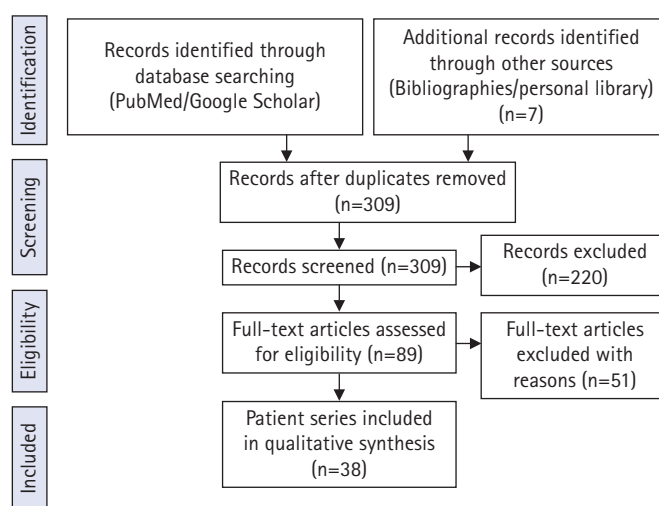
Due to the high variation in relevant articles and anatomical locations, the search was modified to include “cervical, thoracic” which produced 309 results after duplicate articles were identified and discarded.

The search also included the exact surgical technique term “prevalence of symptomatic cervical and thoracic lesion” and returned 89 results published from 1980 to 2021. The exclusion criteria included reported only lumbar lesion (34 articles), deformity (17 articles), primary tumor, metastasis (5 articles), and studies not in English (2 articles). A total of 38 articles that met our inclusion criteria were identified through the search process and were analyzed (Figure 1).

There is no randomized controlled trial (RCT) that can compare prevalence of cervical and thoracic spinal disease, therefore, direct meta-analysis was not possible for both prevalences, and only narrative analysis was performed.

## RESULTS

A total of 38 articles analyzing the prevalence of cervical and thoracic degenerative diseases were finally selected, among



**Figure 1.** Flow diagram (PRISMA format) of the screening and selection process of studies.



which 16 articles were on the prevalence of degenerative stenosis of the cervical spine, 10 articles on the prevalence of OPLL, and 12 articles on the thoracic lesion.

## 1. Prevalence of Degenerative Cervical Spondylotic Myelopathy (Table 1)

In 1997, Moore and Blumhardt [9] reported a prospective

study of non-traumatic spastic paraparesis and tetraparesis in 585 patients. In this study, they found cervical spondylotic myelopathy to be the most common diagnosis (23.6%) in 585 patients admitted to a United Kingdom hospital with tetraparesis or paraparesis.

In 2007, Lee et al. [10] reported anatomic study in cadavers of prevalence of cervical spine stenosis, they estimated that cervical stenosis was present in 4.9% of the adult population, 6.8% of

**Table 1.** Prevalence of cervical spondylotic myelopathy in the reviewed studies

Study	Design	Country	Patient (n)	Sex (M/F)	Age (yr)	Prevalence
Moor and Blumhardt [9], 1997	Prospective	UK	585	N/A	N/A	DCM 23.6% in nontraumatic paraparesis and tetraparesis
Lee et al. [10], 2007	Anatomic cadaver study	USA	469	269/204	331 < 60 138 > 60	Cervical stenosis 4.9% 6.8% of older than 50 years, and 9% of 70s
Bajwa et al. [11], 2012	Anatomical descriptive analysis	USA	1,066	879/187	N/A	Congenital spinal canal stenosis in 250,000 to 500,000 in the USA, among them 20%–25% in the cervical spine
Miyazaki et al. [12], 2014	Retrospective	Japan	145	79/66	69.1	Compressive lesions in anterior parts 23.4%, anterior and posterior parts 23.4%, OLF 31.0%, OPLL 10.3%
Schairer et al. [13], 2014	Retrospective cohort	USA	47,560	269/204	N/A	Cervical spondylosis in 13.1% overall, but in 31.0% of thoracolumbar spinal deformities
New et al. [14], 2014	Literature review	Australia	N/A	N/A	N/A	Degenerative diseases of the spine make up 59% of nontraumatic SCI in Japan, 54% in the USA, 31% in Europe, 22% in Australia, and 4%–30% in Africa.
Boogaarts and Bartels [15], 2015	Literature review	Netherlands	N/A	N/A	N/A	80 of 5,992 patients were operated upon because of a cervical spondylotic myelopathy: 1.6 per 100,000 inhabitants.
Nouri et al. [16], 2015	Literature review	Canada	N/A	N/A	N/A	Prevalence of myelopathy of 605 per million in North America, incidence of cervical spondylotic myelopathy-related hospitalizations at 4.04/100,000 person-years
Nouri et al. [17], 2017	Retrospective	USA	458	285/173	56.4 ± 11.8	Cervical spondylosis was the most frequent cause of DCM with a frequency of 89.7%.
Ko et al. [18], 2018	Prospective	Korea	438	243/195	54.3	Prevalence of cervical foraminal stenosis was highest at the C5–6 level (19.06%), and left C5–6 stenosis was most common (24.66%).
Wada et al. [19], 2020	Retrospective	Japan	146 (farmers) 212 (non-farmers)	69/77 87/125	55.2 53.5	In female farmers, the prevalence of canal stenosis was 50% for participants in their 50s. Over 50% in female non-farmers and males aged 60 and older in both groups, and 9% of the population over 70 years.
Naylor et al. [20], 2020	Retrospective	USA	52	30/22	75.2 ± 7.3	In normal pressure hydrocephalus, 39/52 (75%) had cervical stenosis, and 9/52 (17.3%) had significant (grade 2–3) cervical stenosis with myelopathy.
Liao et al. [21], 2020	Cross-sectional study.	China	7,210	4,546/2,664	54	Prevalence of OPLL in the 7,210 DCM patients was 18.22%, including 19.73% in males and 15.65% in females.
Smith et al. [22], 2021	Systematic review and meta-analysis	UK	3,786	N/A	N/A	Prevalence of asymptomatic SCC in a healthy population was 24.2%, and the prevalence of DCM in a healthy population was 2.3%.
Banerjee et al. [23], 2022	Systematic review and meta-analysis	UK	5,059	N/A	N/A	Prevalence of OPLL (asymptomatic 0.4% vs. symptomatic 10.5%), enlargement of ligamentum flavum (11.8% vs. 56.8%), degenerative multilevel disc (64.5% vs. 89.7%)
Grodzinski et al. [24], 2023	Systematic review and meta-analysis	UK	N/A	N/A	N/A	The mean prevalence of DCM was 0.19% with a peak prevalence of 0.42% at age 50–54 years. The mean prevalence of SCC was 2.22% and the peak prevalence was 4.16% at age > 79 years.

DCM: degenerative cervical myelopathy, OLF: ossification of the ligamentum flavum, OPLL: ossification of the posterior longitudinal ligament, SCC: spinal cord compression, CSM: cervical spondylotic myelopathy.

the population fifty years of age or older, and 9% of the population seventy years of age or older.

In 2012, Bajwa et al. [11] reported anatomical descriptive analysis of congenital cervical spinal stenosis. In this article, it has been estimated that congenital spinal canal stenosis is present in approximately 250,000 to 500,000 people in the United States, of which 20% to 25% are cervical.

In 2014, Miyazaki et al. [12] reported a retrospective study of analysis of the prevalence and distribution of cervical and thoracic compressive lesions of the spinal cord in lumbar degenerative disease. According to this study, in 145 cervical and thoracic spine, compressive lesions from the anterior parts were observed in 34 cases (23.4%). Compressive lesions from the anterior and posterior parts were observed in 34 cases (23.4%). Lesions of ossification of the ligamentum flavum were observed in 45 cases (31.0%). Lesions of ossification of the posterior longitudinal ligament were observed in 15 cases (10.3%).

In 2014, Schairer et al. [13] reported retrospective cohort study of prevalence of cervical spondylosis in patients with adult thoracolumbar spinal deformity. In this study, a total of 47,560 patients were included in this study. Cervical spondylosis occurred in 13.1% overall, but was found in 31.0% of patients with thoracolumbar spinal deformity. Similarly, thoracolumbar spinal deformity was found in 10.7% of patients overall, but was increased at 23.5% in patients with cervical spondylosis.

In 2014, New et al. [14] reported the review article of global maps of non-traumatic spinal cord injury epidemiology: towards a living data repository. In this article, the degenerative diseases of the spine make up 59% of nontraumatic spinal cord injury in Japan, 54% in the United States, 31% in Europe, 22% in Australia, and between 4% and 30% in Africa. In this same review, it was estimated that the regional incidence of nontraumatic spinal cord injury in North America, Europe, and Australia was 76, 26, and 6 per million, respectively, and that the prevalence is 1,120 per million in Canada and 2,310 per million in the Kashmir region.

In 2015, Boogaarts and Bartels [15] reported a review article of prevalence of cervical spondylotic myelopathy. In this study, surprisingly, an extensive search of the literature did not reveal exact data about the incidence or prevalence of cervical spondylotic myelopathy. The prevalence of surgically treated cervical spondylotic myelopathy was estimated as 1.6 per 100,000 inhabitants.

In 2015, Nouri et al. [16] reported the a review article of degenerative cervical myelopathy: epidemiology, genetics, and pathogenesis. In this article, it can be estimated that the incidence and prevalence of nontraumatic spinal cord injury relat-

ed to degenerative cervical myelopathy in the North American region is at a minimum of 41 and 605 per million, respectively.

In 2017, Nouri et al. [17] reviewed magnetic resonance (MR) images of 458 patients with degenerative cervical myelopathy (DCM) and found that cervical spondylosis was most frequent cause of degenerative cervical myelopathy with a frequency of 89.7%. Nearly 60% of spondylosis was accompanied by hypertrophy or enlargement of the ligamentum flavum (LF). Each of single-level discopathy, ossification of the posterior longitudinal ligament (OPLL), and spondylolisthesis had a prevalence with approximately 10%.

In 2018, Ko et al. [18] reported a prevalence of cervical foraminal stenosis (CFS) on computed tomography. In this study, among all 438 patients, left C5-6 stenosis was most common (24.66%), and the most severe stenosis of grade 2 was found in the left C5-6 (2.97%). The prevalence of stenosis at C4-5 was 10.50% on the right side and 13.47% on the left side; at C5-6, it was 13.47% on the right side and 24.66% on the left side; at C6-7, it was 10.96% on the right side and 12.10% on the left side. The prevalence of CFS was high in the following order: left C5-6, left C4-5 and right C5-6, and left C6-7. Overall, the incidence of CFS was greater on the left side than on the right side.

In 2020, Wada et al. [19] reported the prevalence of cervical canal stenosis in farmers. In female farmers, the rate of canal stenosis has already reached 50% among those in their 50s. The rates were over 50% in female non-farmers and males aged 60 and older in both groups. In men, the spinal canal diameter at the C4/5 level was smaller among farmers than non-farmers, and there were no significant differences at other levels. Findings of ossification of posterior longitudinal ligament existed in 5.8% of male and 3.9% of female farmers, and no significant difference in rate was found between farmers and non-farmers in both sexes.

In 2020, Naylor et al. [20] retrospectively reviewed high prevalence of cervical myelopathy in patients with idiopathic normal pressure hydrocephalus. In this study, fifty-two patients shunted for treatment of iNPH were included for analysis. 58% were male with a mean age of 75.2 years (SD 7.3 years). All patients presented with gait disturbances. 39/52 (75%) had cervical stenosis, and 9/52 (17.3%) had significant (grade 2-3) cervical stenosis with myelopathy and were subsequently treated with surgical decompression.

In 2020, Liao et al. [21] reported the overall prevalence of OPLL in the 7,210 DCM patients was 18.22%, including 19.73% in males and 15.65% in females, with a significant difference between the two groups. The prevalence of OPLL in diabetes mellitus (DM) and hypertensive patients was significantly high-

er than that in non-DM and normotensive patients (24.16% vs. 18.76% and 22.26% vs. 17.91%). Comparison by age and body mass index (BMI) showed that the prevalence of OPLL was the highest in the 70- to 79-year age group (21.91%) and obesity group (26.51%), respectively.

In 2021, Smith et al. [22] reported meta-analysis of the prevalence of asymptomatic and symptomatic spinal cord compression (SCC) on magnetic resonance (MR) imaging. The present search returned 1,506 publications. Following our exclusion criteria, 19 studies were included. Subgroup analysis of 3,786 individuals estimated the prevalence of asymptomatic SCC in a healthy population as 24.2% with a significantly higher prevalence of SCC in older populations compared with younger populations and American/European populations compared with Asian populations. A subgroup analysis of 1,202 individuals estimated the prevalence of DCM in a healthy population as 2.3%.

In 2022, Banerjee et al. [23] reported the a review article of the prevalence of DCM-related pathologies on MR imaging. In this meta-analysis study, the search yielded a total of 1,098 studies of which 17 were included in this meta-analysis covering a total of 5,059 patients. According to this study, a prevalence of 0.4% for OPLL, 11.8% of enlargement of LF and 64.5% of degenerative multilevel disc pathology were found to be significantly lower in asymptomatic populations. On the other hand, symptomatic populations have a prevalence of 10.5% for OPLL, 56.8% for enlargement of LF and 89.7% for degenerative multilevel disc pathology.

In 2023, Grodzinski et al. [24] reported meta-analysis of most DCM remains undiagnosed, particularly amongst the elderly: modelling the prevalence of DCM in the United Kingdom. In this article, the mean prevalence of DCM across all age groups was 0.19%, with a peak prevalence of 0.42% at age 50–54 years. This contrasts with estimates from SCC data which suggest a mean prevalence of 2.22% and a peak prevalence of 4.16% at age >79 years.

## 2. The Prevalence of Ossification of Posterior Longitudinal Ligament (OPLL) (Table 2)

In 2012, the prevalence of OPLL has been extensively reported. The early incidence of OPLL based on lateral radiographs was 0.1% to 1.7% in Europe, 0.1% to 1.3% in the United States, 2.1% to 3.0% in Taiwan, 0.6% to 3.6% in South Korea, and 1.9% to 4.3% in Japan [25].

Sasaki et al. [26] utilized plain X-rays to investigate the prevalence and symptoms of OPLL in 1,291 Japanese general resi-

dents, and found that the prevalence of OPLL in symptomatic patients was apparently higher than that in asymptomatic participants (3.9% vs. 2.2%).

With the development of imaging technology and equipment for the spine assessment, the recent OPLL prevalence based on CT was 1.3% to 3.2% in the United States, 5.7% in South Korea, and 6.3% in Japan given that CT has a high sensitivity to OPLL as compared to radiography [27–29] (Figure 2).

Epstein [30] found that about 25% of patients treated surgically for cervical myelopathy exhibited ossification of the posterior longitudinal ligament.

In 2016, Nakashima et al. [31] studied 479 patients with symptomatic DCM based on AO spine cervical spondylotic myelopathy (CSM)-international study database, and found that the overall prevalence of OPLL in patients with DCM was 28.18% and 35.33% in the Asian and Pacific populations, 18.70% in North American populations, and 31.75% in European populations.

Liao et al. [21] reported a cross-sectional study of the prevalence of OPLL in patients with DCM: cervical spine 3D CT observations in 7,210 cases. In this article, the results showed that the prevalence rate of OPLL in patients with DCM was 18.22%, which is much higher than that in the general Asian population as reported in previous studies, indicating that OPLL commonly coexists with degenerative spondylosis in the cervical spine.

In 2016, Fujimori et al. [28] reported prevalence, concomitance, and distribution of ossification of the spinal ligaments: results of whole spine CT scans in 1,500 Japanese patients. In this study, the prevalence of spinal ligament ossifications was found to be 6.3% in cervical OPLL (8.3% in men and 3.4% in women), 23% in ossification of nuchal ligament (ONL) (33% in men and 8.8% in women), 1.6% in thoracic OPLL (1.4% in men and 2.0% in women), 12% in thoracic OLF (15% in men and 7.7% in women), 37% in thoracolumbar ossification of anterior longitudinal ligament (OALL) (45% in men and 26% in women), and 2% in diffuse idiopathic skeletal hyperostosis (DISH) (16% in men and 6.2% in women). Thirteen percent of patients with cervical OPLL had thoracic OPLL, 34% of cervical OPLL had thoracic OLF, 45% of cervical OPLL had ONL, and 36% of cervical OPLL had DISH. The most common level was C5 for cervical OPLL, T1/2 for thoracic OPLL, T11 for thoracic OLF, and T8/9 for OALL.

In 2022, Choi et al. [32] reported in 2020 prevalence, distribution, and concomitance of whole-spine OPLL and OLF in South Koreans. A total of 1,934 adults (1,645 men, 289 women) were included. The mean age was 48.05 years (range, 28–86 years). Among the 1,934 patients, 173 had OPLL (8.9%). The most

**Table 2.** Prevalence of cervical ossification of the posterior longitudinal ligament in the reviewed studies

Study	Design	Country	Patient (n)	Sex (M/F)	Age (yr)	Prevalence
Matsunaga and Sakou [25], 2012	Literature review	Japan	N/A	N/A	N/A	OPLL 1.9% to 4.3% among people older than 30 years in Japan.
Sasaki et al. [26], 2014	Anatomic cadaver study	Japan	1,291	N/A	N/A	Prevalence of OPLL in symptomatic patients was apparently higher than that in asymptomatic participants (3.9% vs. 2.2%).
Fujimori et al. [27], 2015	Cross-sectional study	Japan	3,161	879/187	51.2 ± 21.6	The prevalence of cervical OPLL was 2.2%, 1.3% in Caucasian Americans, 4.8% in Asian Americans, 1.9% in Hispanic Americans, 2.1% in African Americans, and 3.2% in Native Americans.
Sohn et al. [29], 2014	Retrospective cohort	Korea	3,240	1,084/2,156	69.1	OPLL prevalence rate was 5.7%. The standardized prevalence rate was 4.60%. The standardized prevalence rates in men and women were 6.43% and 3.61%, respectively.
Fujimori et al. [28], 2016	Cross-sectional study	Japan	1,500	888/612	N/A	The prevalence of spinal ligament ossifications was found to be 6.3% in cervical OPLL (8.3% in men and 3.4% in women), 23% in ONL (33% in men and 8.8% in women), 1.6% in thoracic OPLL (1.4% in men and 2.0% in women), 12% in thoracic OLF (15% in men and 7.7% in women)
Epstein [30], 2014	Literature review	USA	N/A	N/A	N/A	Prevalence of OPLL in Japan ranged from 1.9% to 4.3% for older than 30 years, Australasia (26/million/yr); Western Europe 6/million/yr; North America 76/million/yr
Nakashima et al. [31], 2016	Prospective	Japan	N/A	N/A	N/A	28.2% had radiographic evidence of OPLL, and 71.8% had other forms of DCM.
Liao et al. [21], 2020	Cross-sectional study	China	7,210	N/A	N/A	Prevalence of OPLL in DM and hypertensive patients was significantly higher than that in non-DM and normotensive patients (24.16% vs. 18.76% and 22.26% vs. 17.91%).
Liang et al. [33], 2019	Cross-sectional study	China	2,000	1,335/665	N/A	In China, the prevalence rate of cervical OPLL was 4.1%, thoracic OPLL 2.25%, lumbar OPLL 0.8%, thoracic OLF 37.65%, lumbar OLF 1.45%, ONL 31.5%, DISH 3.85%.
Choi et al. [32], 2022	Whole-spine-CT-based cross-sectional study	Korea	1,934	1,645/289	48.05	In Korea, prevalence of OPLL was 8.9% (most common in C4, C5, C3, and C6). OLF was observed in 6.5% (most common in T10, T11, and T5). The prevalence of OPLL and OLF was the highest in patients aged 60–69 years

OPLL: ossification of the posterior longitudinal ligament, ONL: ossification of the nuchal ligament, OLF: ossification of the ligamentum flavum, DCM: degenerative cervical myelopathy, DM: diabetes mellitus, DISH: diffuse idiopathic skeletal hyperostosis, CSM: cervical spondylotic myelopathy.

commonly involved cervical vertebra levels arranged according to frequency were C4, C5, C3, and C6. OLF was observed in 125 patients (6.5%). The most commonly involved thoracic levels were T10, T11, and T5. The prevalence of OPLL and OLF was the highest in patients aged 60–69 years. Among the C-OPLL patients, 15.1% had T-OPLL, 5.0% had L-OPLL, and 25.8% had T-OLF.

In 2019, Liang et al. [33] reported epidemiology of ossification of the spinal ligaments and associated factors in the Chinese population: a cross-sectional study. The prevalence rate of cervical OPLL was 4.1%, thoracic OPLL 2.25%, lumbar OPLL 0.8%, thoracic OLF 37.65%, lumbar OLF 1.45%, ONL 31.5%, DISH 3.85%. The most commonly involved level was C5 for C-OPLL, T1 for T-OPLL, T10 for T-OLF, and T8/9 for OALL. 21% of subjects with C-OPLL had T-OPLL, 44% of C-OPLL had T-OLF, 38% of T-OPLL had C-OPLL, 53% of T-OPLL had T-OLF, 44% of L-OPLL had T-OPLL, and 56% of L-OPLL had T-OLF (Figure 3).

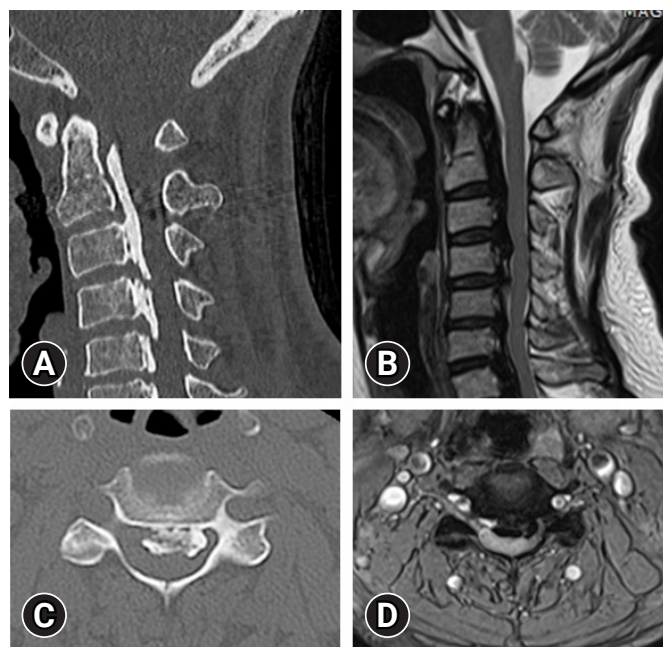
### 3. Prevalence of Thoracic Degenerative Spinal Disease (Table 3)

In 1983, Kudo et al. [34] reported a long-term follow-up investigation of a fixed sample of ossification of thoracic ligamenta flava. In this article, review of 1,744 consecutive lateral chest radiographs identified ligamentum flavum ossification (LFO) in 6.2% of males and 4.8% of females. LFO occurred mainly at the intervertebral segments from T9-T10 through T12-L1. Most prevalent was the hook-shaped LFO, protruding inferiorly from the inferior facets into the projections of the intervertebral foramina. Though LFO can cause severe neurologic symptoms, none of the affected persons in this study reported such symptoms. LFO was first visualized radiographically when the subjects were 20–40 years old, and it may be a physiologic condition.

In 2008, Niemeläinen et al. [35] reported a cross-sectional study of thoracic magnetic resonance image (MRI) findings. In



this study, in the lower thoracic spine, 5.4% to 9.5% of the discs, depending on level, were qualitatively assessed as moderately to severely narrowed. Anterior bulging was more common than posterior, which was relatively rare and mild when present.



**Figure 2.** (A) Cervical reconstruction computed tomography (CT) scan shows a long strip of ossification posterior to the C2-C3 vertebral bodies and mixed configuration at C4-7. (B) Axial CT shows an ossified mass with a hole inside encroaching on the spinal canal. (C) Sagittal T2-weighted magnetic resonance imaging (MRI) shows bandlike low or no signal intensity of an ossified mass compressing the spinal cord at C2-7. (D) Axial T2-weighted MRI shows a huge ossified mass compressing the spinal cord.

Signal was lower in the midthoracic than lower discs. At least 1 moderate or severe vertebral deformity was found in 6.1% of the subjects, suggesting fracture, and hemangiomas were identified in 2.3% of subjects.

In 2014, Miyazaki et al. [12] reported retrospective cohort study of prevalence and distribution of cervical and thoracic compressive lesions of the spinal cord in lumbar degenerative disease. In this article, the DISH was present in 25.6% of patients (72/281). The prevalence of DISH in the 41-49, 50-59, 60-69, 70-79, and  $\geq 80$  year age groups was 8.3% (2/24), 9.8% (5/51), 16.0% (12/75), 49.5% (48/97), and 33.3% (4/12), respectively; the prevalence increased with age. The average number of fused vertebral bodies was 7.5. More than 80% of DISH was located from T7 to T11, and more than 95% of DISH was located at T9/T10. Patients with DISH were significantly older (71.1 years vs. 60.9 years), and men were more likely to have DISH than women.

In 2014, Schairer et al. [13] reported the a retrospective cohort study of the increased prevalence of cervical spondylosis in patients with adult thoracolumbar spinal deformity. In this article, a total of 47,560 patients were included in this study. Cervical spondylosis occurred in 13.1% overall, but was found in 31.0% of patients with thoracolumbar spinal deformity. Similarly, thoracolumbar spinal deformity was found in 10.7% of patients overall, but was increased at 23.5% in patients with cervical spondylosis.

Moon et al. [36] reported prevalence, distribution, and significance of incidental thoracic OLF in Korean patients with back or leg pain. In this study, the prevalence of thoracic OLF in total patients was 16.9% (360/2,134). The prevalence tended to



**Figure 3.** (A) Sagittal computed tomography (CT) scans demonstrating the local ossified ligamentum flavum extending on C4-5. (B) Axial CT scan at the level of C4-5 demonstrating significant posteromedial compression in the spinal canal. (C) Abnormally high T2 signal of the cervical cord opposite the C4-5 level, with the cervical cord being compressed between the right paracentral disc protrusion and abnormal bilateral symmetrical posterior extradural lesions with low signal on all pulse sequences. (D) Abnormally high T2 signal of the cervical cord opposite the C4-5 level, with the cervical cord being compressed between right paracentral disc protrusion and abnormal bilateral symmetrical posterior extradural lesions with low signal on all pulse sequences.

**Table 3.** Prevalence of thoracic spondylotic spinal disease in the reviewed studies

Study	Design	Country	Patient (n)	Sex (M/F)	Age (yr)	Prevalence
Kudo et al. [34], 1983	Retrospective	Japan	1,744	N/A	N/A	Ligamentum flavum ossification (LFO) in 6.2% of males and 4.8% of females
Niemeläinen et al. [35], 2008	Cross-sectional study	Canada	524	524/0	N/A	In the lower thoracic spine, 5.4% to 9.5% of the discs
Miyazaki et al. [12], 2014	Retrospective	Japan	145	N/A	N/A	Compressive lesions in anterior parts in 34 cases (23.4%). Anterior and posterior parts in 34 cases (23.4%). Ossification of the ligamentum flavum in 45 cases (31.0%). Lesions of ossification of the posterior longitudinal ligament were observed in 15 cases (10.3%).
Schairer et al. [13], 2014	Retrospective	USA	47,560	N/A	N/A	Cervical spondylosis occurred in 13.1% overall, but was found in 31.0% of patients with thoracolumbar spinal deformity
Moon et al. [36], 2015	Retrospective	Korea	2,134	867/1,267	56	The prevalence of thoracic OLF in total patients was 16.9% (360/2,134) in Korea.
Park et al. [37], 2015	Retrospective	Korea	476	101/359	83.3	23.9% had concurrent radiologic cervical stenosis and 24.3% had concurrent radiologic thoracic stenosis. 12.1% had combined radiologic cervical and thoracic and lumbar stenosis (triple stenosis). Anterior epidural stenosis at C7-T1 was associated with a high prevalence of thoracic stenosis.
Mori et al. [38], 2016	Cross-sectional study	Japan	68	54/14	65	The distribution of OSIL showed a thoracic preponderance. In OSIL-positive patients, single-level involvement was noted in 19 cases (28%)
Han and Jang [39], 2018	Retrospective	Japan	1,744	N/A	N/A	Prevalence rates of thoracic disc herniation and thoracic hypertrophied ligamentum flavum were 6.5% and 19.0%, respectively.
Siller et al. [40], 2020	Retrospective	Germany	645		70.4	Non-tumorous myelopathy is caused in about 4% of patients by thoracic spinal stenosis.
Chen et al. [41], 2020	Literature review	China	1,935			361 (18.7%) had OPLL, 804 (41.5%) with OLF, 143 (7.4%) with OPLL+OLF and 627 (32.4%) with TDH
Mesregah et al. [42], 2021	Cross-sectional MRI study	USA	10,000			The most common degenerated disc was T6/7 (13.3%), while the least common degenerated level was T12/L1 (1.8%).
Yoshihara et al. [43], 2022	Cross-sectional study		3,299	1,792/1,507	57.6	The prevalence of thoracic OPLL was 1.5% (50 patients), with 2.4% for females and 0.8% for males. The highest prevalence was observed in patients at the age of 70 years (3.8%).

OPLL: ossification of the posterior longitudinal ligament, OLF: ossification of the ligamentum flavum, CSM: cervical spondylotic myelopathy.

increase with aging and was higher in women than in men. The lower thoracic segment of T10-T11 was the most frequently affected segment. Of the 360 patients with OLF, 31.9% had coexisting herniated thoracic discs at the same level. Approximately 74% of the patients with OLF had coexisting lumbar and cervical disease. Nine (2.5%) of 360 OLF patients underwent surgery for thoracic lesion.

Park et al. [37] reported among the 460 patients with lumbar stenosis, 110 (23.9%) had concurrent radiologic cervical stenosis and 112 (24.3%) had concurrent radiologic thoracic stenosis. Fifty-six patients (12.1%) had combined radiologic cervical and thoracic stenosis in addition to their symptomatic lumbar stenosis (triple stenosis). Anterior epidural stenosis at C7-T1 was associated with a high prevalence of thoracic stenosis.

Mori et al. [38] reported prevalence and distribution of ossifi-

cation of the supra/interspinous ligaments (OSIL) in symptomatic patients with cervical ossification of the posterior longitudinal ligament of the spine. In this study, a total of 234 patients with a mean age of 65 years was recruited. The CT-based evidence of OSIL was noted in 68 (54 males and 14 females) patients (29%). The distribution of OSIL showed a significant thoracic preponderance. In OSIL-positive patients, single-level involvement was noted in 19 cases (28%), whereas 49 cases (72%) presented multi-level involvement. We found a significant positive correlation between the OP-index grade and OSI-index. ONL was noted at a significantly higher rate in OSIL-positive patients compared to negative patients

Han and Jang [39] reported prevalence and distribution of incidental thoracic disc herniation (TDH), and thoracic hypertrophied ligamentum flavum. The prevalence rates of TDH and



thoracic HLFS in all patients were 6.5% (145/2,212) and 19.0% (421/2,212), respectively. The prevalence of TDH was demonstrated as a relatively even distribution across age groups higher in male participants (8.0%) than in female participants, and more frequent in patients with lumbar surgical lesions (8.2%) than without surgical lesions. Whereas, the prevalence of thoracic HLFS tended to increase with age, was higher in female participants (21.6%) than in male participants, and had no association with presence of lumbar surgical lesions. The most frequently involved segments of TDH and HLFS were T8/9 and T10/11, respectively. Six of 145 patients with TDH and 15 of 421 patients with HLFS underwent surgery.

In 2020, Siller et al. [40] reported the retrospective study of surgery of degenerative thoracic spinal stenosis-long-term outcome with quality-of-life after posterior decompression via a uni- or bilateral approach. In this study, From 645 patients with surgery for degenerative spondylotic myelopathy within 6 years, 28 patients (4.3%) suffered from thoracic spinal stenosis. Median age was 70.4 years with a slight predominance of the female sex. The most frequent symptoms (mean duration 7.6 months) were ataxia (61%) and sensory changes (50%).

In 2020, Chen et al. [41] reported the review article of the prevalence and clinical characteristics of thoracic spinal stenosis: a systematic review. In this study, a total of 129 studies including 1,935 subjects were selected, of which 361 (18.7%) were diagnosed with OPLL, 804 (41.5%) with OLF, 143 (7.4%) with OPLL+OLF and 627 (32.4%) with TDH. Most reports were from China, Japan and USA. Thoracic OPLL occurred mostly at the middle-thoracic spine (43.4%), while OLF predominately occurred at the lower-thoracic spine (63.1%). TDH was mainly localized in the middle (46.0%) and lower-thoracic (50.3%) spine. Thirty-two studies involving 524 patients described tandem spinal stenosis, of which 52.1% had accompanying cervical diseases and 35.9% lumbar diseases.

In 2021, Mesregah et al. [42] reported a cross-sectional MRI study of trends and patterns of thoracic intervertebral disc degeneration in symptomatic subjects. In this study, the total grade of IVD degeneration and the number of degenerated levels increased with increasing age. The most common degenerated level was T6/7 (13.3%), while the least common degenerated level was T12/L1 (1.8%). The most common grades were grade I in group 1 (60.5%), grade II in groups 2 (39%) and 3 (37.3%), and grade III in groups 4 (42.5%) and 5 (44.6%).

Yoshihara et al. [43] reported prevalence and characteristics of thoracic ossification of the posterior longitudinal ligament in 3,299 Black patients. In this study, the prevalence of T-OPLL was 1.5% (50 patients), with 2.4% for females and 0.8% for

males. The highest prevalence was observed in patients at the age of 70 years (3.8%). Thickness of T-OPLL was between 2 and 3mm in 46% (23/50) of the patients, and the largest thickness was 6.1 mm. T-OPLL was significantly associated with female sex and the presence of DM.

## DISCUSSION

DCM without trauma is the most common cause of spinal cord injury in the elderly population [44]. This DCM largely includes CSM, OPLL, OLF, and degenerative disc disease (DDD).

Tissue degeneration anywhere in the body progresses primarily as a function of the intensity of use over time. However, musculoskeletal structures that bear significant structural loads may be subject to accelerated deterioration.

In the cervical spine, these degenerative changes can be divided into spinal (or osteoarthritic) and non-osteoarthritis changes, with additional subtype classifications. However, although these pathological changes are isolated as separate clinical entities, there are loose differences between them in practical terms, as they are highly interrelated and often appear simultaneously [16].

Ultimately, a major integrative problem is the propensity of degenerative changes to cause spinal canal stenosis, cause spinal cord compression, and eventually lead to disability due to the development of myelopathy.

Pathophysiologically symptomatic DCM can result from static compression of the spinal cord, misalignment of the spine leading to changes in spinal tension and vascular supply, and repetitive dynamic injuries resulting from segmental hypermobility. In the latter case, it has also been recognized that unstable spinal segments can be responsible for chronic repeated microtrauma to the spinal cord that is not large enough to be recognized as traumatic spinal cord injury (SCI) [16]. Additionally, people with spinal stenosis who have experienced minor trauma to the neck have a significantly higher risk of developing myelopathy or worsening an existing myelopathy [45]. Thus, some degree of trauma is likely to contribute to the natural history of DCM development.

One possible way to estimate the incidence and prevalence of DCM is to look at the reported rates of SCI, which are commonly classified as traumatic and non-traumatic forms. DCM is included in these estimates because it represents a non-traumatic form of SCI.

New et al. [14] found that degenerative spinal diseases account for 59% of non-traumatic form of spinal cord injury in Japan, 54% in the United States, 31% in Europe, 22% in Australia,

and 4% to 30% in Africa. In this review article, the regional incidence of non-traumatic form of spinal cord injury was estimated to be 76, 26, and 6 per million in North America, Europe, and Australia, respectively, and the prevalence was estimated to be 1,120 in Canada and 2,310 in the Kashmir region, India. From these figures, the incidence and prevalence of DCM-associated non-traumatic form of spinal cord injury in North America can be estimated to be at least 41 and 605 per million, respectively.

However, these data include the fact that they generally do not include patients with mild symptoms, but only patients with documented paraplegia and quadriplegia due to severe non-traumatic form of SCI. The perception that many patients with myelopathy will have a milder clinical picture indicates that the aforementioned figures are significantly underestimated and likely represent only patients at the severe end of the disease spectrum.

Investigations into the underlying genetic basis for OPLL have been conducted by many researchers. The fact that OPLL is much more frequent in Asian than Caucasian populations supports the presence of a genetic etiological component. In fact, in a nationwide survey of OPLL patients in Japan, it was found that 24% of second-degree relatives and 30% of siblings of OPLL patients had radiographically detectable OPLL [8]. Based on the pathological distribution, OPLL has been classified into four subtypes. Localized, segmental; continuous; mixed with segmental are considered the most common types. Kudo et al. [46] investigated at the genetic differences between these subtypes and proposed two categories for OPLL: continuous (including continuous and mixed) and segmental (including segmental and circumscribed). They concluded that cells from the OPLL contiguous group had a higher osteogenic differentiation potency than cells from the segmental group, and that different genetic backgrounds existed between groups.

Whether there is a genetic susceptibility to future OPLL and cervical degenerative diseases such as ossification of the flavum ligament, whether such susceptibility is genetically distinct from OPLL, and whether there is a generalized spinal ligament ossification condition such as diffuse idiopathic skeletal hyperostosis. It is clear that further research is needed.

## CONCLUSION

Various forms of degenerative cervical spinal disease, including stenosis, which can compress cervical spinal cord and nerve, appear to be very common. Therefore, radiographic findings of cervical spinal stenotic lesions must be correlated with clinical symptoms before making treatment decisions.

DCM is an overarching term used to describe the various degenerative conditions of the cervical spine that result in myelopathy, including CSM, DDD, OPLL, and OLF. Pathophysiologically, symptomatic DCMs result from static compression of the spinal cord, spinal malalignment leading to altered cord tension and vascular supply, as well as dynamic injury mechanisms.

It is important to accurately identify the prevalence of various types of cervical spinal cord and nerve compression disorders and to predict the possibility of neurological symptoms due to progressive degenerative diseases such as ossification in the future. Therefore, accurate diagnosis using CT and MRI requires treatment planning and patient education.

## NOTES

### Ethical statements

This study was exempted from IRB review as it was a study using information disclosed to the general public or a study that did not collect and record personally identifiable information.

### Conflict of interest

Pius Kim is the Editor of the Journal of Minimally Invasive Spine Surgery and Technique and was not involved in the review process of this article. All authors have no other potential conflicts of interest to declare relevant to this article.

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# Endoscopic Approach for A Difficult Cervical Area: Fully Endoscopic Uniportal Transcervical Approach for Ventral Pathologies of the Craniovertebral Junction

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**Objective:** Various pathologies can occur at the craniovertebral junction (CVJ). Posterior decompression with occipitocervical fixation can improve many of these conditions, but anterior decompression is required in some cases. Anterior decompression of a CVJ lesion is very difficult to perform. The transoral approach has been considered the gold standard, but it has the disadvantage of a deep and limited operative field, and many complications are associated with this procedure. Three endoscopic approaches (transoral, transnasal, and transcervical) have been reported previously. Transcervical endoscopic odontoidectomy is a familiar approach for spinal surgeons and can be performed using a uniportal full-endoscopic spinal surgery system.

**Methods:** As described in the present study, 12 patients underwent surgery, and their clinical records were reviewed retrospectively.

**Results:** All patients had good recovery without complications.

**Conclusion:** Fully endoscopic uniportal transcervical odontoidectomy has many advantages for ventral pathologies of the CVJ. In particular, it can avoid heat injury despite drilling very close to the brainstem in deep closed lesions.

**Key Words:** Craniocervical, Full-endoscopic spinal surgery, Odontoid process

## INTRODUCTION

The craniovertebral junction (CVJ) is one of the most complex cervical areas. Decompression of this area is difficult, and consensus on the surgical methods is yet to be reached. The open transoral approach has for long been the only technique

for ventral pathologies at the CVJ, but other minimally invasive techniques have been developed. Endoscopic procedures are especially common in this field. In particular, Full-endoscopic uniportal transcervical endoscopic odontoidectomy is a highly useful method, and we report this surgical method compared to other surgical treatments.



## MATERIALS AND MEYHODS

### 1. Indication

The surgical strategies vary depending on the pathology. Pseudotumors usually increase in size in the presence of CVJ instability or overload. Therefore, recurrence may occur after direct anterior decompression. Transcervical odontoidectomy is indicated in cases in which posterior decompression and fixation are performed; however, a decrease in the pseudotumor size is not observed. In the case of bony compression, such as a basilar impression, transcervical odontoidectomy is indicated when symptoms cannot be improved via posterior decompression and fixation. Bony compression, which does not require fixation, is also indicated.

### 2. Surgical Procedures

#### 1) Anesthesia and Patient Position

The patient was placed in the supine position under general anesthesia (Figure 1A). In this position, it is easier to manipulate the endoscope during transnasal intubation. The head was fixed by a Mayfield head clamp. When a patient has posterior occipitocervical fixation (OCF), the neck should be in a neutral position. The neck position of the patient without a previous OCF should be slightly extended.

#### 2) Preoperative Procedures

Biplane fluoroscopy is sufficient to confirm the intraoperative

orientation; however, a navigation system with intraoperative cone-beam CT is quite useful (Figure 1B). The navigation reference was attached to a Mayfield head clamp. We used a lateral fluoroscope and navigation system simultaneously.

#### 3) Skin Incision and Insertion of Endoscope

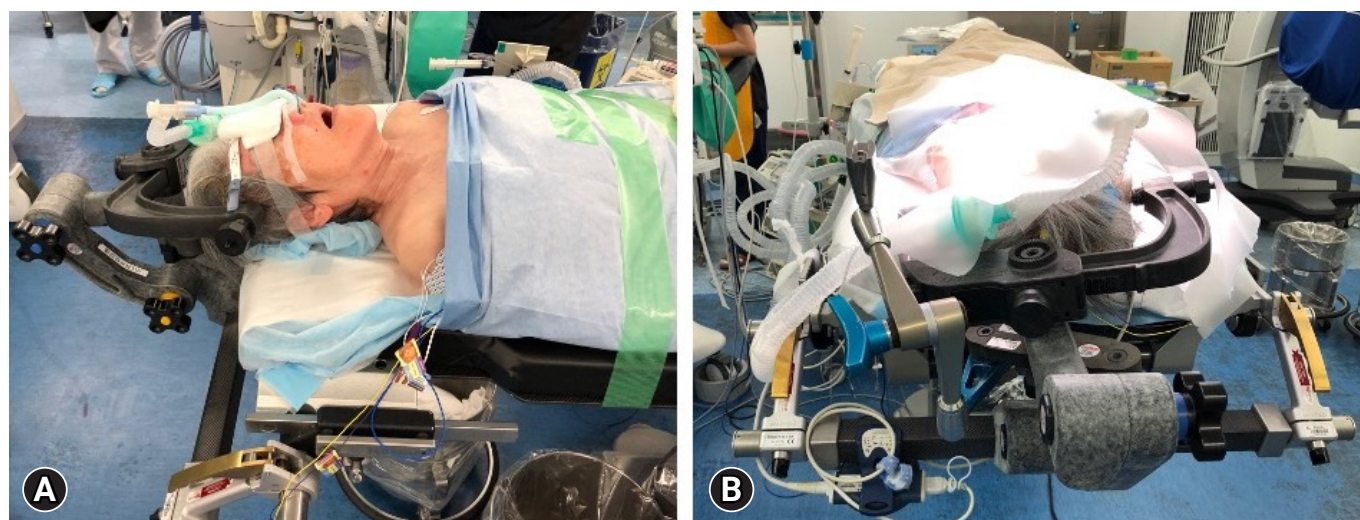
A 4-cm transvers linear skin incision was made on the right side of the anterior cervical, which position was majored by preoperative radiography, depending on the insertion angle of the endoscopic approach. The ventral surface of C2 to the subaxial vertebrae was exposed, as in the open anterior cervical approach. A single-port endoscope was inserted through an open-skin incision.

#### (1) Surgical procedures

There are two strategies that depend on the decompression area: partial and total odontoidectomy (Figure 2).

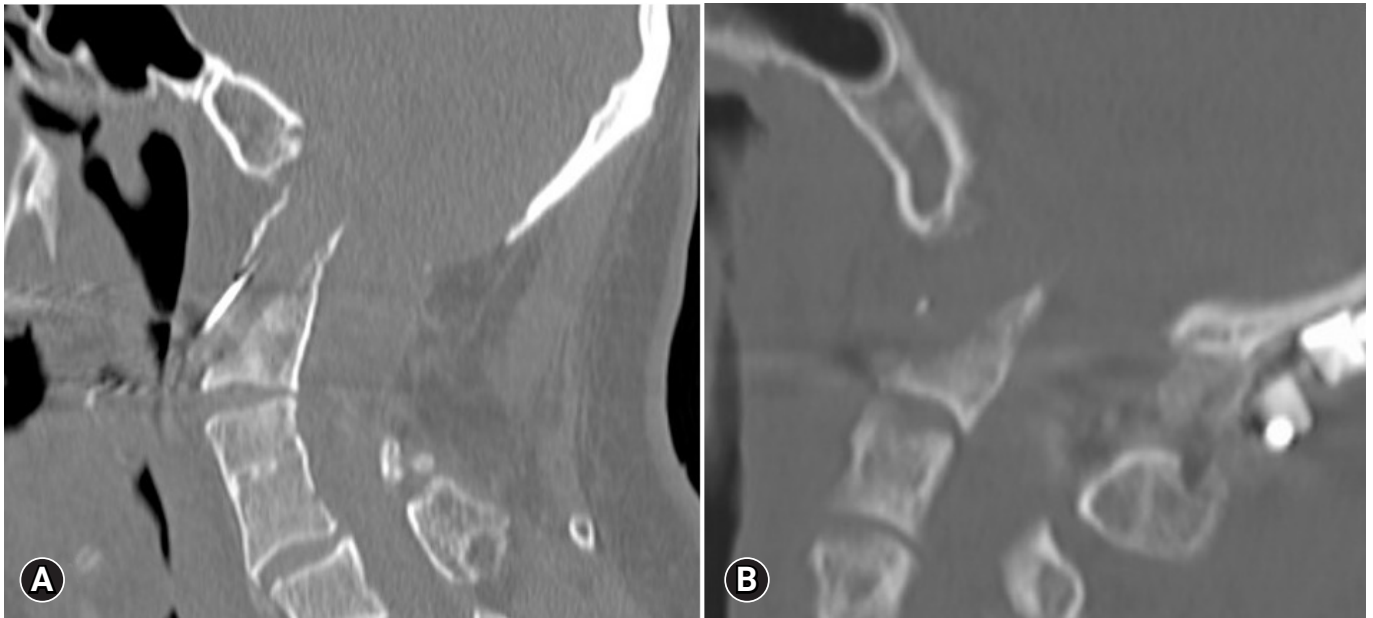
#### (2) Partial odontoidectomy

This strategy is for cases with pseudotumors or compression by the odontoid tip or dorsal wall (Figure 3). The starting point of drilling was the midline just above the C2/3 disc space (Figure 4A). After making an 8-mm hole to insert the outer sheath, the cancerous bone was drilled by rotation of the outer sheath (Figure 4B) and an electrical drill under direct endoscopic view and biplane fluoroscopy (navigation is helpful in this procedure). The cortical bone (dorsal wall of the dens) was then recognized. The selected area that was planned preoperatively was drilled to decompress under a lateral fluoroscope. The pseudotumor

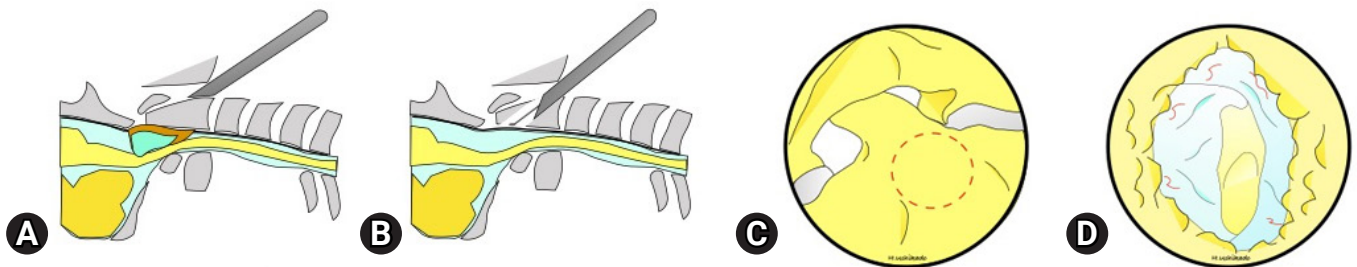


**Figure 1.** (A) A patient is placed in the supine position. The head is fixed by a head clamp. (B) Navigation reference is attached at the head clamp.

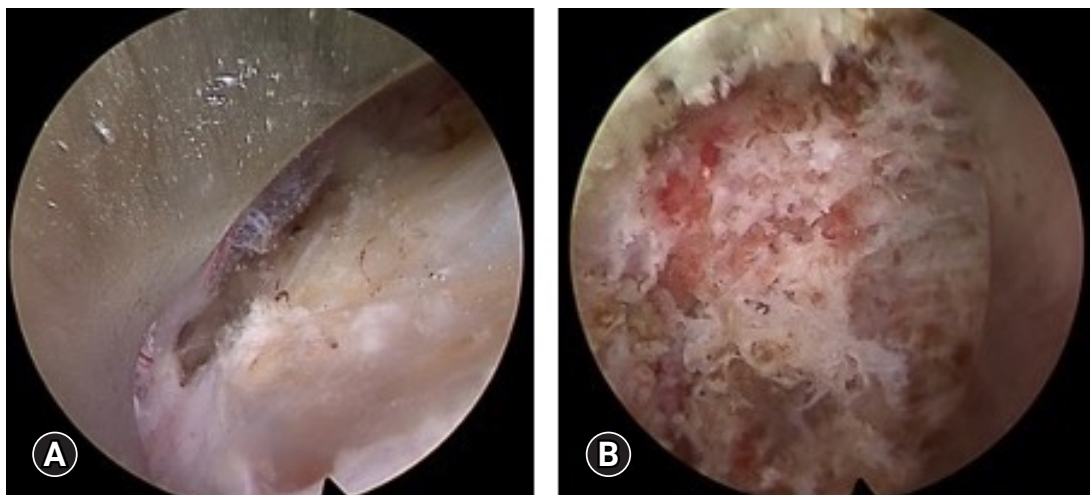




**Figure 2.** (A) Postoperative CT scan after partial odontoidectomy. (B) Postoperative CT scan after total odontoidectomy. CT: computed tomography.



**Figure 3.** (A, B) Schema of the lateral view. (C) Drilling area. (D) After cyst resection. Pulsation of the soft tissue was confirmed.



**Figure 4.** Intraoperative views step by step. (A) The odontoid tip was recognized. (B) The cancellous bone was drilled under the guidance of the fluoroscope and navigation system.

was located behind the transverse ligament. For patients with pseudotumors, the odontoid tip was drilled to the dorsal wall of the dens. Yellowish connective tissue, like hypertrophied yellow ligament, was found behind the dens. Decompression of the soft tissue, including the cyst, was performed. After complete hemostasis, a drain tube was inserted into the dens, and the wound was closed in the usual manner.

### (3) Total odontoidectomy

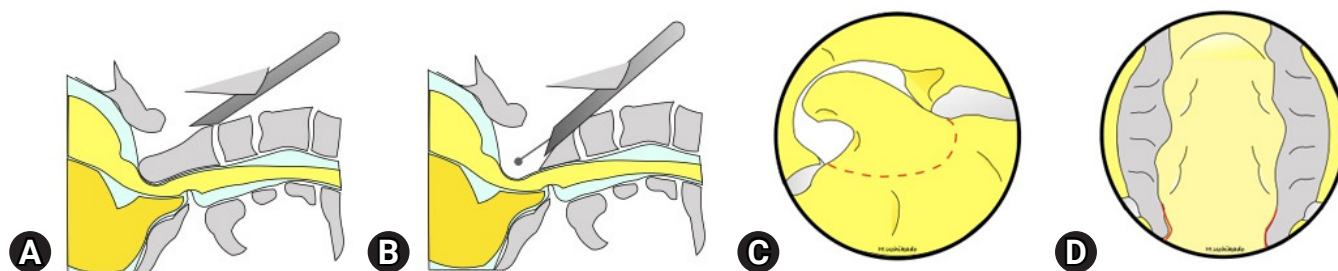
The first bilateral edge of the dens was confirmed. Drilling was started at the base of the dens. The decompression area was examined using a lateral fluoroscope (Figure 5). The caudal end of the clivus was confirmed after a complete resection. We do not cut tectal membrane or posterior longitudinal ligament to decompress to expose dura matter. A drain tube was inserted, and the wound was closed.

### (4) Final checking point

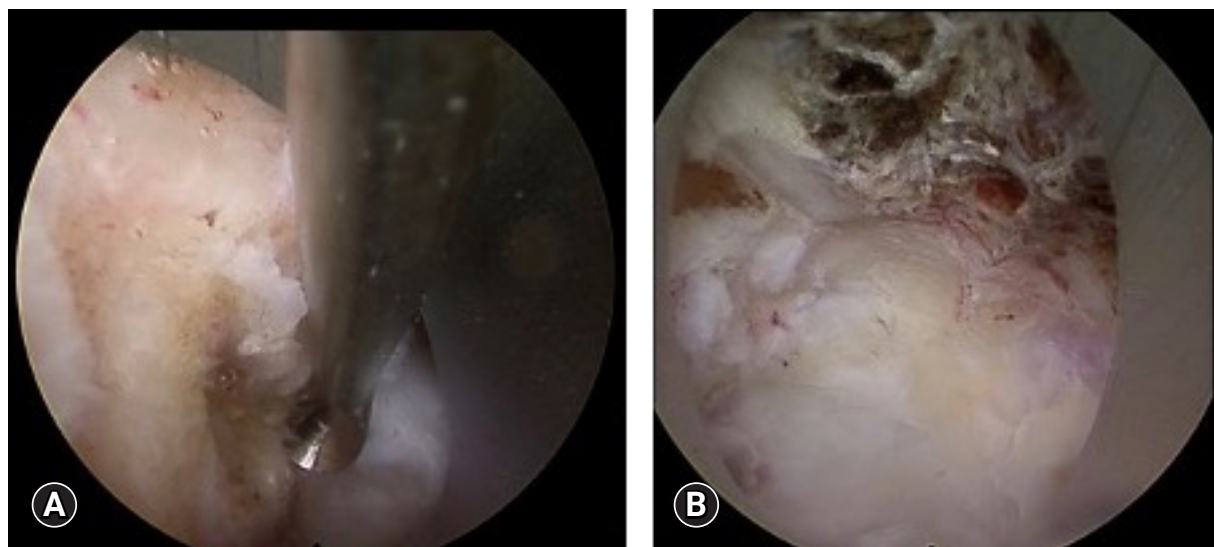
After decompression, soft tissue pulsation was recognized. Decompression area was confirmed by direct tactile perception (Figure 6). The decompression area was also confirmed using a biplane fluoroscope or navigation system (Figure 7). Corn-beam CT is also useful for confirming the decompression.

## RESULTS

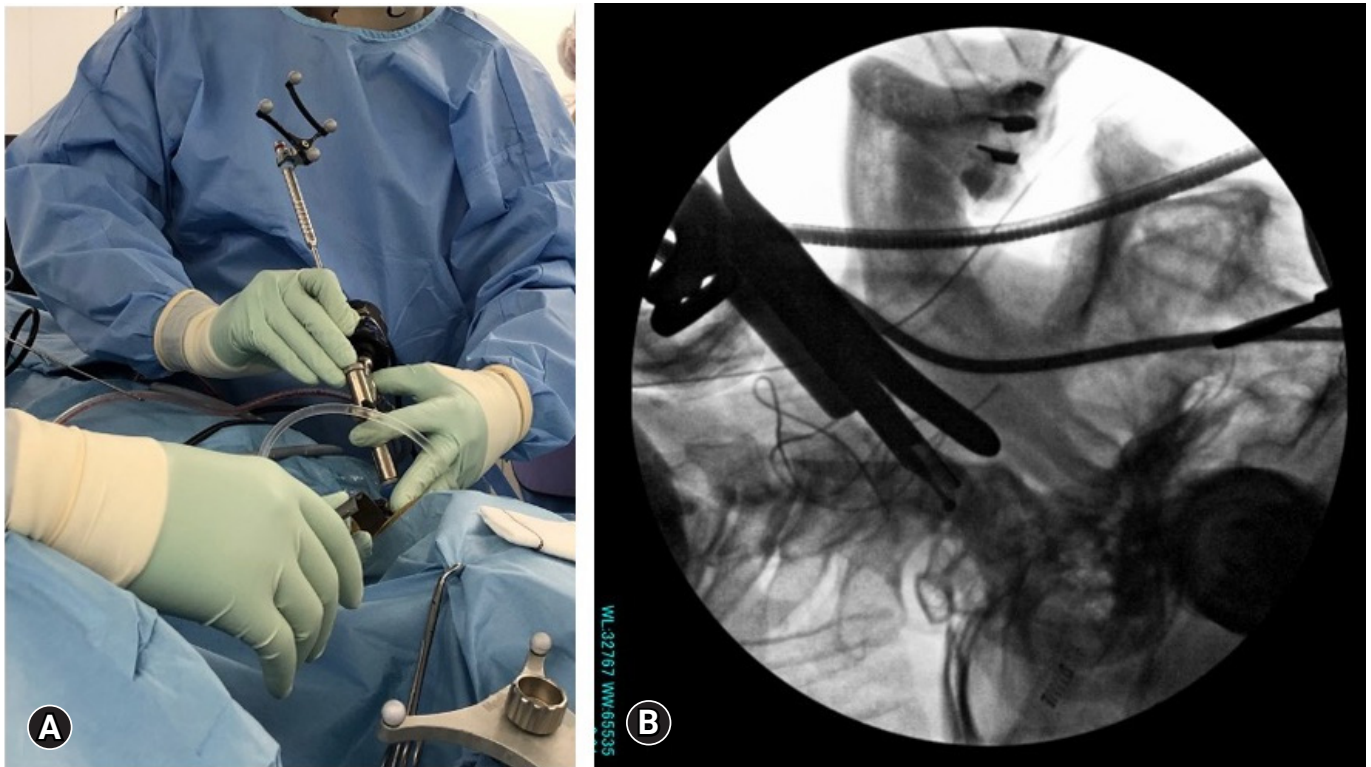
Twelve patients were operated on using transcervical endoscopic odontoidectomy (Table 1): seven cases of basilar impression (BI) and five cases of pseudotumor (cases 1–3 were reported in a previous case report [1]). There were seven men and five women (men/women=3/4 in BI, 4/1 in pannus). The mean age was 62.3 (39–77) years and 77.2 (71–81) years, respectively. Nine patients underwent surgery after OCF, and three patients did not undergo OCF. The mean operative time



**Figure 5.** (A, B) Schema of the lateral view. (C) Drilling area. (D) After cyst resection. Pulsation of the soft tissue was confirmed.



**Figure 6.** Intraoperative views step by step. (A) The right side of the bone edge was confirmed directly by a curved curette. (B) The odontoid tip and dorsal wall of the dens were resected.



**Figure 7.** (A) Confirmation by navigation system. (B) Intraoperative lateral fluoroscope.

**Table 1.** Case series

	Age (yr)	Sex	Pathology	Operative time (min)	EBL	Follow-up (mo)	Fixation
1	72	Man	BI	300	Small	44	OCF
2	39	Woman	BI	343	Small	37	OCF
3	78	Man	Pannus	205	Small	38	OCF
4	71	Woman	BI	220	Small	30	OCF
5	71	Man	Pannus	93	Small	30	OCF
6	77	Woman	BI	220	Small	28	OCF
7	77	Woman	Pannus	106	Small	25	OCF
8	64	Woman	BI	138	Small	24	OCF
9	59	Man	BI	134	Small	20	OCF
10	79	Man	Pannus	170	Small	20	None
11	53	Man	BI	189	Small	18	None
12	81	Man	Pannus	164	Small	7	None

BI: basilar impression, OCF: occipitocervical fixation.

was 190.2 min (189 min in BI and 147.6 min in pseudotumor). Extra blood loss was not significant, and no complications were observed in all cases. All patients showed improvements in myelopathy and brainstem symptoms after surgery. Additional OCF was required in Case 12 because of pseudotumor recurrence. This patient rejected OCF first and wanted to undergo only decompression surgery but finally accepted OCF during the second surgery.

## DISCUSSION

Reumatoid arthritis (RA) and its anomalies are the main pathologies of brainstem dysfunction at the CVJ. The pseudotumor increased not only the instability of the CVJ but also the overload at the CVJ caused by the stiffness of the subaxial cervical spine. Usually, compression pathologies at the CVJ arise from the anterior region, but many cases improve after posterior decompression and fixation [2]. Some cases required



odontoidectomy after the posterior procedure, and the gold standard of ventral decompression at the CVJ, open transoral approach, was considered. Many authors have reported the disadvantages of the transoral approach [3], which include a limited operative view and a deep working distance. In addition, the transoral approach is associated with several risks, such as contamination by normal oral flora, dehiscence of the surgical wound, alteration in phonation, tongue edema, the potential need for prolonged intubation or tracheostomy, the requirement of avoiding oral intake, and postoperative enteral tube feeding.

Three approaches to endoscopic odontoidectomy have been proposed to resolve these complications of transoral approach [4]. First, the transoral endoscopic approach is useful for vertical long mass lesions at the CVJ to below C2 [5,6]; however, it cannot control the contamination of the oral flora. Second, the transnasal endoscopic approach [4,7-9], which was initiated by a skull base surgeon, allows many instruments to be used in large natural anatomical cavities, but the caudal view is limited. The third method is the transcervical approach and was first reported in endoscopic-assisted surgery using the METREX system [10]. Wolinsky et al. [10] reported many advantages of this approach: spine surgeons are familiar with the technique, it does not require traversing the oral mucosa, the deepest basilar invaginations can be decompressed because their trajectory is parallel to the odontoid itself, and it does not require resection of anterior arch of atlas. The transcervical approach has disadvantages that are almost the same as those of the anterior cervical open procedure. Odontoidectomy under full endoscopic spinal surgery was reported by Ruetten et al. [11]. They referred to this technique as “full-endoscopic uniportal technique using retropharyngeal approach.” They reported three papers on this approach [11-13], and another author reported a case series of the same procedure [1]. These studies mentioned that the merit of this technique is its large working area. The caudal limitation of mobility is in the lower jaw, and transnasal intubation is helpful. Occasionally, cranial limitations are encountered in patients with barrel chest. Resection of the C1 anterior arch is useful in solving this problem. Expected complications are almost the same as those of open anterior cervical approach, such as the original transcervical odontoidectomy using METREX system by Wolinsky et al. [10].

In addition to familiarity to spine surgeons, transcervical has many advantages compared to other decompression procedures. Complications associated with the anterior cervical approach are easily imaged and avoided. The decompression area can be selected depending on the pathology of each pa-

tient in this approach. Some patients, such as those with BIs, require total odontoidectomy, but not all patients require total odontoidectomy. If the anterior arch of C1, the anterior wall, and part of the lateral wall of the dens are preserved, the risk of instability at C1/2 might be decreased. Heat injury might occur by drilling deep-sheeted lesions. The uniportal endoscope provided a closed, clear view under saline irrigation. Continuous saline irrigation helps with cooling. This system is the most suitable instrumentation for deep closed site drilling.

No complications were observed in this case series; however, the number of cases in this study was small. Cases with ventral pathologies are very rare, especially those that cannot be improved by posterior decompression and fixation. Further studies are required to determine the efficacy and safety of this approach.

## CONCLUSION

Pathologies of the CVJ are usually treated using the posterior approach. However, some cases cannot be improved by posterior decompression and fixation because of severe ventral compression pathologies. Full-endoscopic transcervical ventral decompression of the CVJ is useful in these cases. This procedure does not require a special approach and is familiar to spine surgeons. The main point of this technique is the strategy for decompression. It is important to understand which cases require partial or total decompression of the odontoid. In addition, the characteristics of each instrumentation should be understood to ensure selection of good indications for instrumentation.

## NOTES

### Ethical statements

This study was approved from the ethical committee of Juntendo University (C21-0065).

### Conflict of interest

Yukoh Ohara is the Editor of the Journal of Minimally Invasive Spine Surgery and Technique and was not involved in the review process of this article. All authors have no other potential conflicts of interest to declare relevant to this article.

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# Outpatient Fully Endoscopic Cervical Unilateral Laminotomy for Bilateral Decompression with Virtual Postoperative Monitoring

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**Objective:** Cervical endoscopic unilateral laminotomy for bilateral decompression (CE-ULBD) is a promising novel surgical approach. However, to date, there is a paucity of data regarding safety, efficacy, and functional outcomes following CE-ULBD.

**Methods:** The aim of this study was to investigate the outcomes of outpatient CE-ULBD combined with postoperative smartphone-based continuous physiological monitoring and virtual follow-up.

**Results:** We included a total of 23 patients in our study group. The mean age was  $69.1 \pm 2.5$  years. A significant postoperative reduction of the visual analogue scale for neck pain ( $4.1 \pm 0.6$  pre- vs.  $2.3 \pm 0.5$  post-surgery;  $P < 0.0001$ ) and upper extremity pain ( $2.6 \pm 0.6$  vs.  $1.1 \pm 0.3$ ;  $P = 0.0012$ ) was reported alongside a significant improvement in the Neck Disability Index ( $18.6 \pm 2.5$  vs.  $9.1 \pm 2.5$ ;  $p = 0.032$ ). Eleven patients were monitored with continuous physiological monitoring via a smartphone app (SPINEHealthie). Those patients were more likely to be outpatients ( $p = 0.0002$ ) and less likely to have postoperative inpatient clinic utilization ( $p < 0.0001$ ). Continuous physiological monitoring suggested a trend towards higher levels of function in patients following CE-ULBD.

**Conclusion:** Our early results suggest that outpatient CE-ULBD followed by virtual postoperative monitoring is a safe and efficient therapeutic intervention for symptomatic cervical spinal stenosis.

**Key Words:** endoscopic, laminotomy, Telemedicine

## INTRODUCTION

Spinal stenosis is present in 9% of individuals seventy years of age or older [1]. The development of spinal cord dysfunction is thought to be multifactorial, with both static and dynamic factors involved in the pathogenesis. Static factors comprise

degenerative disc disease, osteophytes, facet hypertrophy, or ossification of the posterior longitudinal ligament [2]. Dynamic factors, such as repetitive flexion and extension of the spinal column during physiological body movements, cause repetitive dynamic microtrauma [3,4]. Additionally, movement and pathological interactions of the cerebrospinal fluid and



the spinal cord have been reported at and beyond the level of stenosis, adding an oscillation component to the microtrauma theory [5-8]. Combined mechanical strain leads to hypoperfusion of the spinal cord, resulting in the loss of neurons and myelin through a cascade of neuroinflammatory processes and apoptosis [9,10]. Patients frequently first notice progressive loss of dexterity caused by degenerative cervical myelopathy. Besides that, neck pain, alongside sexual, bladder and gait dysfunction are common symptoms of degenerative cervical myelopathy [11].

Therapeutic approaches include conservative measures like physical and occupational therapy, cervical traction, and medication (i.e., steroids and nonsteroidal anti-inflammatory drugs) [12]. Surgical interventions have been reported to alleviate symptoms with an overall improvement in both functional and quality of life measures [13]. The general concept of all surgical approaches is the decompression of the spinal cord. Anterior discectomy and fusion (ACDF) is a well-established and effective surgical procedure. However, it is more suitable to one- or two-level pathologies, and patients may experience transient or permanent dysphagia after surgery [14,15]. Open posterior decompression and fusion as well as laminoplasty are other treatment options that address posterior pathologies effectively. Disadvantages of these procedures include significant blood loss, wound healing issues, non-union and persistent neck pain [16]. Full endoscopic spine-surgery (FESS) on the other hand presents a minimally invasive alternative to the aforementioned procedures [17]. While FESS has been described as efficacious and safe, especially with regards to an aging population [18] data supporting it as an effective mean for cervical spine decompression remain scarce. We previously reported on a novel FESS technique to decompress the spinal cord via a unilateral laminotomy for bilateral decompression (CE-ULBD) [19], allowing the surgeon to achieve a bilateral decompression through a unilateral laminotomy [20].

The scope of this paper was to further define the safety, efficacy, and objective functional impact (stepping data) of CE-ULBD. Additionally, we aim to present our early experience with virtual follow-up and asynchronous patient-provider communication using a novel smartphone application (SPINEhealthie).

## MATERIALS AND METHODS

For this retrospective analysis, we included patients receiving CE-ULBD for symptomatic single- or multilevel central

canal stenosis at the Department of Neurological Surgery at the University of Washington. Patients of >18 years were included when reporting preoperative neck pain and/or other symptoms of cervical myelopathy comprising loss of dexterity, gait dysfunction, sexual and/or bladder dysfunction, and radiating upper extremity pain alongside confirmation of central canal stenosis through magnetic-resonance-imaging (MRI). Patients reporting sole upper extremity pain and patients with foraminal stenosis were not considered for CE-ULBD. Patients gave written and informed consent preoperatively. Outcome measures were acquired through the SPINEhealthie application as well as the electronic patient chart. Relevant parameters were predefined and reviewed. They consisted of the patients' demographics, patient-reported outcome measures (PROMs), imaging, and operative details. PROMs consisted of a visual analogue scale (VAS) for both neck and upper extremity pain [21], as well as the Neck Disability Index (NDI) [22]. In example, patients using SPINEhealthie get a reminder through their smartphone to report the aforementioned PROMs through the applications interface. Patients without SPINEhealthie were asked to complete a questionnaire incorporating the respective PROMs.

### 1. Post-Surgical Follow Up

Patients were offered either traditional inpatient follow-up or virtual follow-up using our SPINEhealthie smart phone application. SPINEhealthie allows for a continuous, asynchronous remote patient monitoring. In brief, the patient can report PROMs daily and is able to contact their respective provider via a chat function. Additionally, it allows for post-operative follow-up examinations to be carried out virtually. The application collects basic demographic information such as age, gender, and body-mass-index (BMI). Procedures are named according to the AOSpine Nomenclature for Working-Channel Endoscopic Spinal procedures [19]. Participating patients gave written and informed consent and were introduced to the applications use in general as well as the chat function and image transmission process. Patients were asked to report their PROMs at different timepoints. We assessed the demographics, a visual analogue scale (NRS) for neck and leg pain and the neck disability index (NDI) as parameters for the functional outcome [19]. Patients can synchronize their stepping data with the application as well. For patients without SPINEhealthie, the postsurgical PROMs were acquired through the electronic patient chart.

2. Surgical Techniques

All procedures were performed by the same, experienced surgeon as previously described [20]. In brief, all patients underwent general anesthesia. Subsequently, electrophysiological monitoring was set up and recorded throughout the entire procedure. Monitoring included motor evoked potentials and somatosensory evoked potentials. The patients were positioned in a prone position the patient’s head was secured with Mayfield® head holders. Through anteroposterior (AP) and lateral fluoroscopic guidance, mediolateral and rostrocaudal approach trajectories were determined. For CE-ULBD, saline at room temperature is used for irrigation. Fluid is delivered to the working area with precise control of the flow rate and hydrostatic pressure by a specialized fluid pump (Versicon®, Joimax). Our initial default settings are 40 mmHg of pressure at a rate of 0.4 L/min for cervical decompression surgery. In order to correct for bed height and patient size, the endoscope is raised approximately 50 cm above the surgical field, which should result in cessation of flow. The irrigation pressure is then adjusted accordingly using the “level” function on the fluid pump. The vertical skin incisions at the previously located and marked locations were carried out using a #11 blade. After careful, blunt preparation of the subcutaneous layers, serial dilators were advanced on the lamina followed by tubular retractors. We then brought the endoscope (iLESSYS® Pro, Joimax® Inc, Irvine, CA), with a 4.7 mm working channel diameter and 7.3 mm outer diameter. Paraspinal muscles were dissected using a Bovie cautery. The laminectomy was performed using a 3.5 mm diameter diamond burr and a #3 Kerrison rongeur. The yellow ligament was resected piecemeal using both micro punch and rongeur. An adequate decompression was confirmed by the identification of the ipsilateral thecal sac and dural pulsations. Analogously, the contralateral side was decompressed using the same working channels via an over-the-top decompression. Upon completion, the wound was copiously irrigated, and meticulous hemostasis was obtained with gelfoam powder and the radiofrequency probe. No wound drainage was inserted post-surgery (Figure 1).

3. Statistical Analysis

Continuous variables were analyzed as means±standard error of the mean (SEM). Categorical variables are depicted as frequency distributions or fractions of total (%). Repeated measurements were compared using a paired-samples t-test. For categorical variables, simple logistic regression and a multiple

logistic regression adjusted for age and gender were performed. Statistical calculations were carried out and graphs designed using GraphPad Prism (Version 9.5.0; GraphPad Software, Boston, MA 02110; ©2023).

RESULTS

Our patient cohort included a total of 23 patients (7 female, 16 males) with a mean age of 69.1±2.5 and a BMI of 28.4±1.1 (Table 1). Patients presented with a variety of symptoms. The main complaints were neck pain (87.0%), gait instability (26.1%) and dexterity impairment (21.7%). Pre-operative imaging revealed single- (43.5%), bisegmental (43.5%), and multilevel stenosis (13.0%) with C5/6 being most affected (Table 1).

All patients tolerated the CE-ULBD surgery well. On average, 1.7 spinal levels were decompressed, and the duration of the surgery was 129.5±10.9 minutes (Table 2). The estimated blood loss was minimal with 8.2±4.2 mL. One patient with extremely severe spinal stenosis, had reduction of her motor evoked potentials, and displayed a transient post-surgical neurological deficit that subsided within the first month after sur-

Table 1. Patient demographics (n=23)

Parameter	
Sex	
Female	7 (30.4%)
Male	16 (69.6%)
Age (SEM)	68.9 ± 2.5
BMI (SEM)	28.4 ± 1.1
Comorbidities:	
Hypertension	9 (39.1%)
Hyperlipidemia	7 (30.4%)
Diabetes	0 (0%)
Coronary artery disease	2 (8.7%)
Presenting symptoms:	
Neck pain	20 (87.0%)
Upper extremity pain	14 (60.1%)
Gait instability	6 (26.1%)
Loss of dexterity	5 (21.7%)
Number of stenotic levels:	
One	10 (43.5%)
Two	10 (43.5%)
Multi-level	3 (13.0%)
Anatomical location	
C2/3	3 (13.0%)
C3/4	10 (43.5%)
C4/5	8 (34.8%)
C5/6	12 (52.2%)
C6/7	7 (30.4%)

SEM, standard error of the mean; BMI, body mass index.

gery. No other surgical complications were reported.

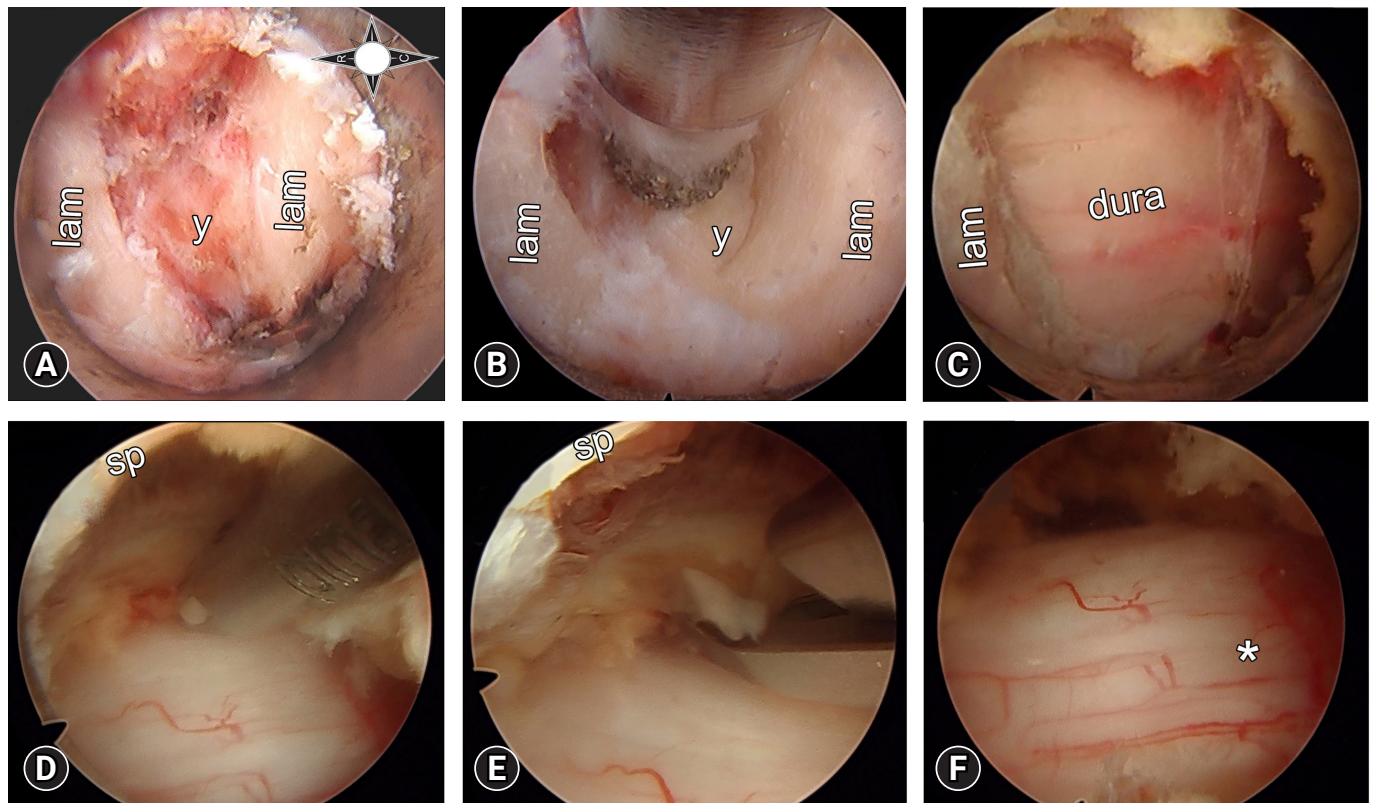
None of the patients suffered from postoperative deterioration or new permanent neurological deficits. Same day discharge was feasible in 43.4% of our patients. In our cohort 56.5% of patients elected to stay overnight in the hospital. The longest post-operative hospital stay was 2 days. One patient with active polysubstance abuse returned to the emergency department 12 days after surgery for a femur fracture that required surgery. Eleven patients in our cohort opted for virtual

follow-up using SPINEhealthie smartphone app.

At the last point of follow up  $15.6 \pm 2.4$  weeks after the surgery, patient enjoyed a significant decrease in the neck pain compared to baseline ( $4.1 \pm 0.6$  vs.  $2.3 \pm 0.5$ ;  $p < 0.0001$ ). Additionally, there was a significant decrease in the pain for the upper extremity ( $2.6 \pm 0.6$  vs.  $1.1 \pm 0.3$ ;  $P = 0.0012$ ; [figure 2](#)). Importantly, CE-ULBD resulted in significant improvement of the neck disability index ( $18.6 \pm 2.5$  vs.  $9.1 \pm 2.5$ ;  $p = 0.032$ ). Univariate logistic regression revealed a significantly lower rate for post-surgical hospitalization ( $p = 0.0002$ ) and in-person follow-ups ( $p < 0.0001$ ) for patients using the SPINEhealthie app. Objective pre- and postoperative stepping data was available for 4 patients ([Figure 2](#)). When compared to the pre-operative baseline, the patients displayed a tendency towards improved function as indicated by an increase in mean daily steps from  $4,054 \pm 2,177$  to  $4,247 \pm 2,082$ .

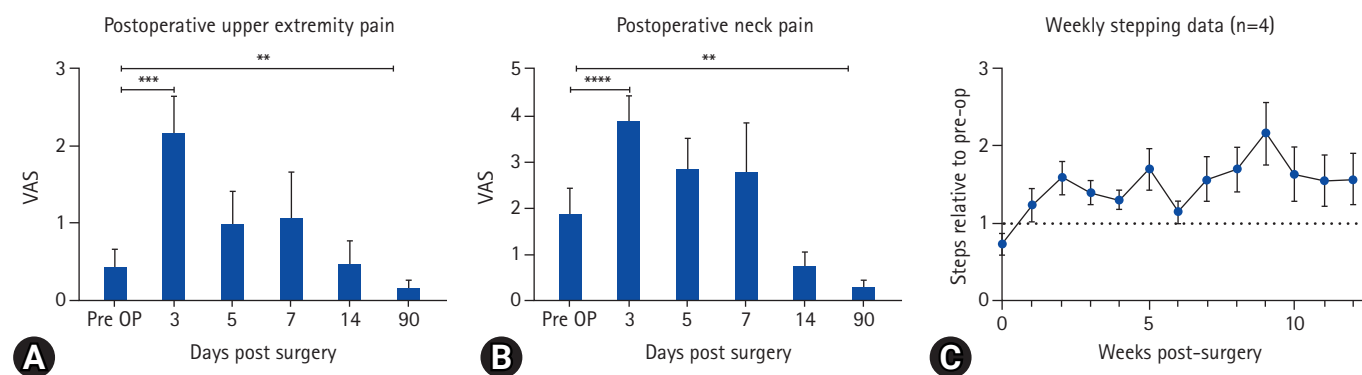
**Table 2.** Perioperative data (n=23)

Parameter (SEM)	
No of operated levels	1.7 (0.2)
Estimated blood loss (mL)	8.2 (0.9)
Duration (min)	129.5 (10.9)
Hospitalization	13 (56.6%)
SPINEhealthie app	11 (47.8%)
In-person follow-up	12 (52.2%)
30-day readmission	1 (4.3%)

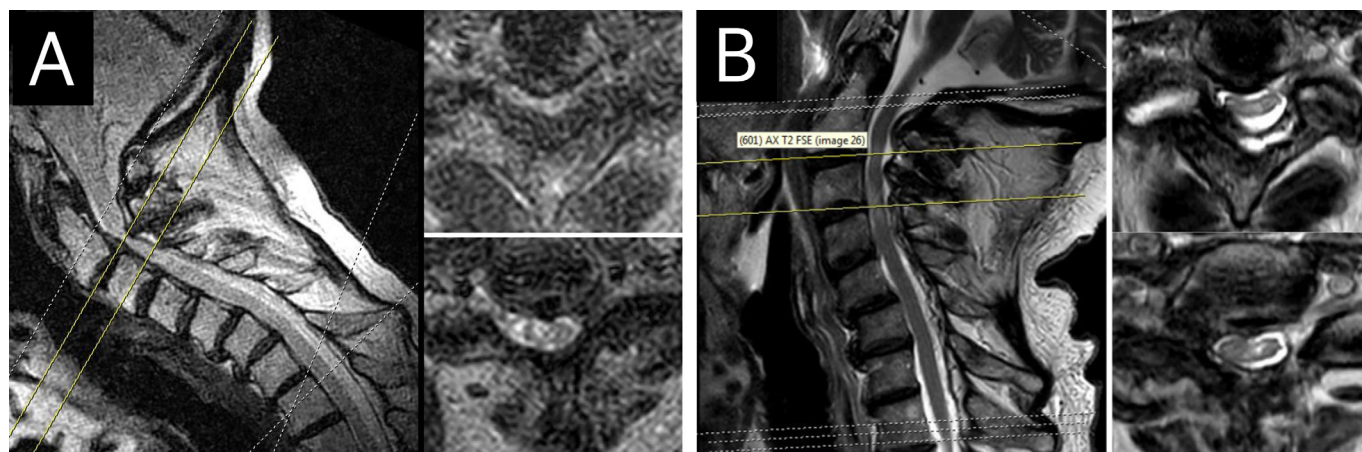


**Figure 1.** Intraoperative images during FESS. The initial endoscopic view depicts the juxtapsed edges of the index level laminae (lam) with connective tissue in between (A). A hemi-laminotomy is initiated by drilling along the juxtapsed edges of the laminae (B). The ipsilateral spinal cord is decompressed once the hemi-laminotomy is completed (C). The spinous process is generously undercut with the high-speed burr and yellow ligament is resected piecemeal using a micropunch (D) and Kerrison rongeur (E). Complete circumferential decompression of the dorsal thecal sac is achieved (F). FESS: fully endoscopic spinal surgery. \* = dura, lam = lamina, y = yellow ligament, sp = spinous process.





**Figure 2.** Patient outcomes. The graphs depict the postoperative pain development for the first week after surgery. For the first 3 days, a significant increase in both upper extremity ( $p < .0001$ ) (A), and neck pain (B), can be seen. At the last point of follow-up, a significant decrease in pain when compared to the preoperative baseline is seen for both upper extremity pain ( $p = 0.0005$ ) (A), and neck pain ( $p = 0.01$ ) (B). (C) The graph shows patients' weekly average stepping data ( $n = 4$ , with the standard error of the mean) relative to their 90-day preoperative stepping average (interrupted line). Reported are the first 12 weeks post-surgery.



**Figure 3.** Magnetic resonance imaging (MRI) before and after cervical decompression. Depicted is an MRI scan of a patient with cervical two-level spinal canal stenosis at the C2/3 and C3/4 junction with T2-signal changes of the spinal cord. Cross-sectional images show (A) stenosis (B) and images of the same patient after CE-ULBD. The decompression can be seen directly and indirectly, as indicated by the patency of the subarachnoid space. CE-ULBD, cervical endoscopic unilateral laminotomy for bilateral decompression.

## DISCUSSION

### 1. The Surgeon's Perspective

FESS has been successfully utilized for decades. Unilateral laminotomy for bilateral decompression has shown excellent results in the lumbar spine, effectively relieving leg and back pain while improving functional outcomes [23–25].

For the cervical spine, the bilateral decompression via unilateral laminotomy constitutes a relatively recent treatment strategy (Figure 3). The paramedian technique we propose, as previously described, allows for a safe approach while easing the

surgeon's anatomical orientation [20]. During the surgical spinal cord decompression, the integrity of the spinal cord needs to be protected by the surgeon. Any accidental advancement of the tubular retractor, endoscope or tool onto the spinal cord could result in irreversible neurological deficits. In our series, one patient experienced transient post-operative neurological deficits. In conclusion, we believe that, if conducted by an experienced FESS-surgeon, this procedure poses a safe alternative to other, traditional techniques. Additionally, FESS offers several benefits when compared to the traditional, open procedures, as it has been described as less invasive, preserves spinal stability allowing to omit stabilization [26], and shows favorable

results regarding complication rates [18]. Additionally, here we propose that stepping data might constitute a promising tool to monitor post-surgical progress objectively and continuously.

## 2. The Patient's Perspective

Our results highlight the efficacy of CE-ULBD in significantly reducing the reported pain scores for the included patients in both neck and upper extremity. While there is a significant increase in the pain-levels within the first three days after surgery, the short-term functional outcomes as evidenced with significantly better NDI-score and a tendency towards better mobility, are encouraging for both the patient and the surgeon. While continuous physical therapy and self-reliant exercises are still imperative, we strongly believe that patients can benefit from our full endoscopic approach that mitigates some disadvantages of traditional spine surgery. Importantly, CE-ULBD is a minimally invasive outpatient procedure and is thought to have little effect onto adjacent motion segments. If necessary, traditional surgical options such as disc arthroplasty, anterior cervical discectomy, or fusion or posterior traditional decompression and stabilization remain viable treatment options in case additional treatment of the index level is necessary.

## 3. The Hospital's Perspective

As surgeons, we strive to do what we believe is best for our patients. Considering limited resources in every healthcare system, simultaneous efficiency and mindfulness are required, too. Outpatient treatment after spine surgery has been shown to be cost effective when compared to inpatient treatment options [27,28]. With the focus on the lumbar spine, an influx in ambulatory surgeries has been described over the last decades without a simultaneous rise in postsurgical complications [29,30]. While some authors describe the safety of outpatient treatment after anterior cervical spine surgery [31,32], data concerning the posterior approach is lacking. Our study suggests no increase in clinic utilization after outpatient surgery. In fact, we show a significant decrease in clinic utilization after the introduction of the SPINEhealthie app, indicating that a continuous virtual patient monitoring post-surgery is an effective tool to optimize the clinics resources without putting patient's safety at risk. The safety of the proposed procedure is underlined by the extremely low rate of emergency room utilization post-surgery in our group. In fact, outpatient treatment has been linked to a lower emergency room department utilization [33]. Lastly, the reduction of in-clinic visits is favorable from an economic

standpoint and more convenient for the patient [34]. In fact, the COVID pandemic and the concomitant difficulties in providing in-patient visits, highlighted the necessity for a paradigm shift with possibilities for safe, virtual follow-ups.

## 4. Limitations

Main limitation of this study is the small cohort size. Moreover, it is a single center single surgeon study. Our ongoing efforts collect PROMs and mobility data in several academic centers using the SPINEhealthie app.

## CONCLUSION

The presented data highlights the safety and effectiveness of the CE-ULBD in combination with virtual follow-ups. Importantly, we propose objective stepping data as a possible method to monitor postoperative recovery.

## NOTES

### Ethical statements

Not applicable.

### Conflicts of interest

No potential conflict of interest relevant to this article.

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# A Narrative Review of Biportal Endoscopic Spine Surgery in the Cervical and Thoracic Spine: Insights into Its Capabilities, Limitations, and Possibilities

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Biportal spinal endoscopy has been successfully utilized for the surgical treatment of common spinal conditions, mainly in the lumbar spine. Surgeons recently have translated this technique to the cervical and thoracic spine. Little is known regarding the clinical effectiveness and safety profile of the biportal endoscopic technique in the cervical and thoracic spine. This is a narrative review of the applications of biportal spinal endoscopy in the cervical and thoracic spine, discussing its current capabilities, limitations, and possible future applications.

**Key Words:** Biportal endoscopy, Spinal endoscopy, Endoscopic spine surgery, Cervical stenosis, Thoracic stenosis

## INTRODUCTION

Biportal spinal endoscopy is an emerging minimally invasive technique in spine surgery with mounting evidence of clinical effectiveness and safety, mainly in the lumbar spine [1-4]. Biportal spinal endoscopy utilizes a water-based endoscope that is separated from the surgical instruments, in contrast to full endoscopy (uniportal), which incorporates the camera with the working channel altogether. Both techniques incorporate water-based irrigation systems that allow for enhanced visualization using endoscopic cameras. However, by separating the endoscope from the surgical instruments through separate incisions, the biportal technique allows for greater freedom and flexibility, allowing for greater applicability in the spine.

The potential benefit of the biportal endoscopic technique

includes reducing the soft tissue trauma from surgical dissection, thereby improving postoperative pain and recovery, and optimizing visualization of the surgical anatomy to reduce iatrogenic injury to the spinal and neural structures. This safety aspect is extremely important given the potential risk to the spinal cord in the cervical and thoracic spine. Thus far, the biportal technique has been applied to posterior cervical and thoracic approaches for treatment of cervical disc herniations, foraminal stenosis, cervical central stenosis, cervical extradural cysts, and calcified thoracic ligamentum flavum causing spinal cord compression. We will provide a narrative review of the application of the biportal technique to the cervical and thoracic spine and consider the inherent capabilities and limitations and discuss the possible applications of the technique.

## CERVICAL DISC HERNIATION AND FORAMINAL STENOSIS

Cervical disc herniations and foraminal stenosis can be successfully treated in a myriad of different ways from anterior cervical discectomy and fusion (ACDF), cervical disc replacement (CDR), and posterior laminoforaminotomy with discectomy. Posterior laminoforaminotomy can be successfully performed using the biportal endoscopic technique without the complete removal of the intervertebral disc that would be required with ACDF and CDR. Much of the available studies on biportal endoscopy in the cervical spine is centered on cervical disc herniations and foraminal stenosis, likely due to the relative safety of the technique given the anatomic location of disc herniations and foraminal stenosis.

Park et al. [5] published one of the earliest reports of utilizing the biportal endoscopic technique for cervical disc herniations in 2017. The authors described the short-term results of 13 patients with mean follow up of 14.8 months. In this study, clinical outcome scores improved significantly with Visual Analog Score (VAS) neck, VAS upper arm, and Neck Disability Index (NDI) scores ( $p < 0.05$ ), using biportal endoscopy for cervical discectomies (Table 1). The authors commented that the procedure may be an alternative procedure for the treatment of cervical disc herniations but larger studies with longer follow-up was required.

A technical note was published by Song and Lee [6] with preliminary results of 7 patients who underwent biportal endoscopic posterior cervical inclinatory foraminotomy for cervical radiculopathy. The authors utilized the technique of posterior cervical inclinatory foraminotomy to preserve the facet joint and prevent iatrogenic instability. The diagnoses included cervical disc herniation as well as foraminal stenosis. The mean follow-up was short at  $6.42 \pm 2.99$  months. Postoperative MRI and CT scans demonstrated successful removal of disc herniations and neural decompression in all the treated segments without any significant change in the cervical alignment, segmental dynamic angle, or disc space height. VAS scores and

NDI scores improved significantly from preoperative visit to the final follow-up visit,  $p < 0.05$  (Table 1). There was 1 dural tear that was successfully treated with gelfoam and fibrin sealant patch and no instances of neurological complications including dysesthesia or motor weakness in their small series (Table 2).

Jung and Kim [7] published the largest case series to date of utilizing biportal spinal endoscopy for single level cervical disc herniations. Their study included 109 consecutive patients, 84 males and 25 females with mean age of 54.5 years. C5-6 and C6-7 were the most common operated levels ( $n=41$ ,  $n=45$ , respectively). Clinical follow-up was performed up to 24 weeks post-operatively and clinical outcome scores improved significantly (Table 1). Patient satisfaction using the Macnab criteria was 86.2% "good to excellent" at 24 weeks after surgery. There were no major complications other than 1 case of C5 nerve root palsy with longitudinal fluid retention in the dorsal epidural space on the postoperative MRI (Table 2). The palsy improved over 4 weeks with conservative management. There were no recurrences or reoperations during the follow-up period. The authors commented on the favorable outcomes with few complications, but the procedure is challenging to master due to the steep learning curve.

The study with the longest follow-up to date was published by Kang et al. [8] who performed a retrospective review of 65 consecutive patients with cervical foraminal stenosis causing cervical radiculopathy with 1 year follow-up. In addition, the authors compared the results of full endoscopy to biportal en-

**Table 2.** Summary of the published studies depicting the complication profiles of biportal spinal endoscopy for cervical disc herniation and foraminal stenosis

Study	Reported complications for biportal endoscopy
Park et al. [5]	None
Song et al. [6]	1 dural tear
Jung et al. [7]	1 C5 nerve root palsy
Kang et al. [8]	1 dural tear, 1 epidural hematoma and persistent dysesthesia
Kim et al. [9]	2 recurrence (1 ACDF), dural tear, transient nerve root palsy

**Table 1.** Summary of the published studies depicting the clinical outcomes of biportal spinal endoscopy for cervical disc herniations and foraminal stenosis

Study	Number of patients	Follow-up	VAS neck (preoperative)	VAS neck (postoperative)	VAS arm (preoperative)	VAS arm (postoperative)	NDI (preoperative)	NDI (postoperative)	p-value
Park et al. [5]	13	14.8 mo	$6.2 \pm 0.8$	$2.4 \pm 0.9$	$7.0 \pm 1.1$	$2.2 \pm 0.6$	$27.0 \pm 2.5$	$6.8 \pm 1.4$	$< 0.05$
Song et al. [6]	7	$6.42 \pm 2.99$ mo	N/A	N/A	$7.71 \pm 0.75$	$0.85 \pm 0.69$	$60.85 \pm 26.85$	$10.57 \pm 5.74$	$< 0.05$
Jung et al. [7]	109	24 wk	$6.6 \pm 2.1$	$1.1 \pm 0.8$	$7.2 \pm 2.4$	$1.0 \pm 0.7$	$43.8 \pm 15.3$	$6.1 \pm 5.5$	$< 0.001$
Kim et al. [9]	30	$11.7 \pm 6.4$ yr	$4.3 \pm 1.6$	$1.0 \pm 0.5$	$7.6 \pm 0.7$	$0.8 \pm 1.0$	$26.2 \pm 2.5$	$1.3 \pm 4.4$	$< 0.001$

VAS: visual analog score; NDI: neck disability index.

doscopy with 32 patients undergoing full endoscopy versus 33 patients with biportal endoscopy. All patients in the study had significant improvement of VAS neck and arm scores as well as NDI scores, and no difference of clinical outcomes scores between the 2 endoscopic techniques. Patient satisfaction using the modified Macnab criteria was good to excellent in 91.7% of patients in the full endoscopy cohort versus 87.9% in the biportal cohort.

One case in each cohort required reoperation due to incomplete decompression with the patient who underwent full endoscopy revised to ACDF and the biportal patient revised with another biportal procedure. There was one case of incidental durotomy in each cohort and one case with C5 nerve root palsy in the full endoscopy cohort (Table 2). There was one case of epidural hematoma as well as persistent dysesthesia in the biportal cohort (Table 2). These patients improved with conservative management. The authors concluded that both endoscopic techniques were successful in clinical outcomes and relatively safe with low complication rates.

Another comparative study was published by Kim et al. [9] who compared radiologic and clinical outcomes for full endoscopy, biportal endoscopy, and microsurgery for posterior cervical foraminotomy for foraminal stenosis. Clinical outcome scores improved significantly in the biportal group from preoperative to final follow-up (Table 1). The authors found that the biportal technique had a low complication profile that was comparable to the other techniques (Table 2).

The safety of the posterior laminoforaminotomy for treatment of cervical disc herniations and cervical foraminal stenosis is favorable from these studies given the location of the compressive lesions away from the central spinal canal and spinal cord and closer to the foramen and nerve root. Thus far in the literature, this is the ideal indication for biportal endoscopy in the cervical spine.

## CERVICAL CENTRAL STENOSIS

Only a few case reports have been published thus far in the scientific literature on performing biportal endoscopy for decompression of cervical central stenosis. Typically, cervical stenosis causing spinal cord compression is treated with ACDF, anterior cervical corpectomy and fusion, cervical laminectomy and fusion or cervical laminoplasty. The posterior approaches with cervical laminectomy and fusion and cervical laminoplasty are associated with significant neck pain and disability in open surgery due to posterior cervical muscle stripping and dissection with retraction of the musculature that is required

for visualization. Biportal endoscopy may provide a minimally invasive option to decompress the spinal cord while preserving the posterior cervical musculoligamentous structures, potentially reducing post-operative pain and disability. However, there are significant safety concerns with this technique due to risks to the spinal cord especially in the setting of pre-existing spinal cord compression.

A description of the biportal technique for unilateral laminotomy and bilateral decompression for the treatment of cervical spondylotic myelopathy was published by Kim et al. [10]. The authors presented a case of C5-6, C6-7 central stenosis with compression of the spinal cord due to ligamentum flavum hypertrophy and disc protrusions seen on MRI. CT imaging demonstrated ossification of the posterior longitudinal ligament at C5-6. Unilateral laminotomy and bilateral decompression was performed at C5-6 and C6-7 to decompress the spinal cord at these levels. The patient improved with motor weakness and radiating pain in the bilateral upper extremities and postoperative MRI demonstrated complete decompression of the central canal. The authors commented that this technique can be used in highly selective cases of cervical stenosis with myelopathy due to hypertrophied ligamentum flavum, cervical stenosis with concomitant foraminal stenosis, and cervical stenosis with OPLL. They reserved the technique to select patients who are poor candidates to conventional surgeries due to medical conditions since the surgery is technically difficult with a steep learning curve, as well as the risk for spinal cord injury. The authors recommended en-bloc resection of the lamina and ligamentum flavum to reduce the risk of spinal cord injury.

Zhu et al. [11] published a technical note on adding a third portal for biportal endoscopic decompression for cervical spondylotic myelopathy (CSM). The purpose of the third portal was to assist the decompression of the contralateral side of the spinal canal. The biportal technique was utilized on the ipsilateral side while the third portal was placed on the contralateral side. After completing the decompression on the ipsilateral side, the endoscopic camera and the radiofrequency probe were taken to the contralateral side through the interspinous ligament. The third portal was then utilized to perform the decompression on the contralateral side.

The study cohort consisted of 6 patients with single level cervical stenosis causing CSM with mean follow-up of  $6.2 \pm 3.3$  months. Postoperative MRI demonstrated complete decompression in all cases. There was one case of transient hypoesthesia of the contralateral hand that resolved over time. The mean Japanese Orthopaedic Association (JOA) score improved from  $7.5 \pm 3.8$  preoperatively to  $12.1 \pm 5.2$  at the final follow-up

( $p > 0.05$ ). All 6 patients reported excellent satisfaction based on the modified Macnab criteria. The authors purport that the use of the third portal makes the procedure easier and safer to decompress the contralateral spinal canal.

Zhu et al. [12] also published a case report of performing bilateral biportal endoscopic open door laminoplasty that was stabilized with suture anchors. Biportal endoscopy was performed on one side for placement of the suture anchors and the creating the partial laminoplasty trough for the hinge side. Suture anchors were placed at the center of the lateral mass and spinous process at C4, C5, and C6. Biportal endoscopy was then performed on the contralateral side to create the full laminoplasty trough and to raise the lamina. The endoscopic equipment was then passed over the lamina through the interspinous ligament to the hinge side and a third portal was utilized to secure the suture anchors. Postoperative CT and MRI were performed to verify enlargement of the cervical canal and complete decompression. JOA and NDI scores improved clinically from the authors' report.

In addition to the biportal endoscopic laminoplasty with suture anchors, Zhu et al. [13] described using biportal endoscopy to perform unilateral biportal endoscopic laminectomy with lateral mass screw fixation in a case report. After biportal endoscopic exposure of the left laminae of C4, C5, and C6, separate portals for the right side were made to expose the lamina and lateral masses on the right side. The start point for the lateral mass screws were identified with a 2-mm diamond burr and fluoroscopy, then two 3.5-mm polyaxial screws were inserted through the screw portals. After screw placement, a rod and set screws were placed into the lateral mass screws. At this point, the remnant spinous processes were removed with a grinding drill and the laminae were thinned down to the ventral cortex, which was removed with a 1-mm Kerrison rongeur. Postoperative CT and MRI imaging verified correct placement of the implants and complete decompression at C4-5. The patient had significant improvement of the numbness and gait dysfunction post-operatively. The authors recommended that surgery should be converted to open procedure if the endoscopic visualization or screw trajectory became difficult.

The biportal endoscopic technique can also be used for removal of cervical extradural cysts causing cervical central stenosis. Kim et al. [14] presented 2 cases of using biportal endoscopy to address weakness and cervical radiculopathy from intraspinal, extradural cysts compressing the spinal cord and cervical nerve roots. After placement of the biportal endoscopic equipment and exposing the lamina, a laminotomy was performed with an endoscopic diamond drill. The drilling pro-

ceeded until there was free epidural space surrounding the cyst. The ligamentum flavum was carefully dissected off the cyst and the cyst were carefully dissected off the dura to be removed en bloc. Postoperatively, the neurological deficits and symptoms of cervical myeloradiculopathy improved with no recurrence of symptoms at 10-12 months post-operatively. Postoperative MRI and CT demonstrated complete removal of the cyst and decompression of the spinal cord. The authors contended that the endoscopic camera under continuous irrigation provides a clear magnified surgical view that enabled them to manipulate the anatomy to remove the cyst successfully and safely. They acknowledged that the steep learning curve is an impediment to widespread implementation of the technique and the technique should be reserved for select patients with experienced surgeons only.

## THORACIC STENOSIS

Little has been published in the use of biportal endoscopy for thoracic stenosis. The earliest study of utilizing biportal endoscopy in the thoracic spine was published by Osman et al. [15] in 2012 and was a case series of 15 consecutive patients with symptomatic thoracic disc herniations. He described the use of arthroscopic equipment to triangulate into the posterolateral aspect of the thoracic disc through the foramen from the lateral to medial direction. After exposure of the posterolateral annulus, an annulotomy was performed under endoscopic visualization and a discectomy is performed with decompression of the epidural space. The authors then described placement of bicortico-cancellous bone dowels from the iliac crest into the disc space for thoracic interbody fusion. The VAS back score improved significantly and 11 out of 15 patients were satisfied with their quality of life post-operatively as compared to 1 patient preoperatively. Postoperative CT scans demonstrated successful fusion in all patients and there were no complications in this study. The hospital costs averaged \$8,208.20 as compared to \$15,849.69 for thoracotomy surgery. The authors contended that this biportal technique is less invasive, cost-effective, and clinically effective method to address thoracic disc herniation.

Other applications of biportal endoscopy in the thoracic spine include resection of ossified ligamentum flavum (OLF) causing spinal cord compression. Kang et al. [16] published a technical report and described the technique for unilateral laminotomy with an endoscopic drill with a diamond head tip. Once the laminotomy was complete and the dura was exposed, the boundaries of the OLF were identified. The drill was utilized to make a paper-thin plate of the OLF in contact with the dura



and the adhesions were released with a small nerve probe. The remnant of the OLF was then resected and confirmed by pulsation of the dura. The authors recommended that the biportal technique be utilized only in select patients depending on the morphology of the OLF. Certain large types may require open laminectomy and dural reconstruction depending on the size and characteristics of the OLF.

The largest case series on the use of biportal endoscopy for the treatment of OLF was published by Deng et al. [17], who compared the biportal cohort with open surgery. The biportal cohort consisted of 14 patients for a mean follow-up of 15.4 months vs the open cohort, which had 45 patients and a mean follow-up of 37 months. Surgical time and hospital stays were significantly less with the biportal cohort as compared to the open cohort with significant improvements in clinical outcomes scores,  $p < 0.001$  (Table 3). Postoperative CT and MRI showed decompression of spinal cord and complete resection of OLF lesions. There was no neurological deterioration seen in the biportal cohort at the one-year follow-up. The authors found that the biportal cohort had few complications but had 2 cases of headache and neck and back pain, which may be due to excessive epidural pressure from the endoscopic irrigation. These authors also excluded large OLF types from the biportal cohort, shifting bias against the open cohort as more difficult and complex cases were completed open while the smaller lesions were addressed with the biportal technique. Nevertheless, the authors contended that the biportal technique is safe and effective for the treating OLF in the thoracic spine.

Jing et al. [18] published a case report describing a “cave-in” decompression with biportal endoscopy for upper thoracic ossification of posterior longitudinal ligament (OPLL). The authors presented a case of T1-3 OPLL causing spinal cord compression leading to gait disturbance and lower extremity motor weakness. The decompression was carried out in 2 stages with the first stage consisting of excision of the ipsilateral lamina,

facet joint, partial transverse process, and pedicles of T2 and T3 with exposure of the dural sac margin using biportal endoscopy. The second stage consisted of removal of OPLL and decompression of the spinal cord after creating 2 additional portals using incisions that were more far lateral in an approach that mirrors a costotransversectomy approach. The OPLL and posterior vertebral bodies were partially resected with a high-speed drill and a cave within the posterior vertebral body was created from one side to the other until the OPLL was separated from the body completely. An eggshell layer of OPLL that was adherent to the dura was released and the remnants of the OPLL were excised. There was no CSF leak or worsening motor strength postoperatively and the patient recovered significant lower limb function. The postoperative modified JOA score was 7 as compared to 5 preoperatively. Postoperative CT and MRI images demonstrated removal of the OPLL and decompression of the spinal cord.

Much work is required for biportal endoscopy to become a viable treatment option for thoracic stenosis. Well-designed clinical studies with long term follow-up are necessary to demonstrate clinical effectiveness with the biportal technique in the thoracic spine. The biportal technique can reduce the morbidity of the surgery as compared to open techniques due to the very minimally invasive nature of the biportal endoscopy. Patients may avoid larger surgery such as open laminectomy, partial thoracic corpectomy and fusion to address thoracic spine pathology and may improve with pain and function expeditiously after surgery. Table 4 summarizes the advantages and disadvantages of the biportal technique for both cervical and thoracic cases.

## SAFETY CONSIDERATIONS FOR CERVICAL AND THORACIC CASES

The application of biportal endoscopy for cervical and tho-

**Table 3.** Summary of the clinical results by Deng et al. [17] comparing biportal spinal endoscopy and open surgery for ossification of ligamentum flavum causing thoracic stenosis

Surgery type	Age (yr)	Number of patients	Operative time (min)	Hospital stay (d)	VAS leg (preop)	VAS leg (postop)	mJOA (preop)	mJOA (postop)	Complications
Biportal	59.4 ± 9.3	14	66.1 ± 15.4	4.9	4.5 ± 2.0	0.8 ± 0.8	6.2 ± 1.2	8.6 ± 0.9	1 with severe CSF leak and postural headache, 2 with headache and pain in the back and neck, 2 with hyperalgesia of lower limbs
Open	56.2 ± 6.7	45	125.0 ± 29.9	15.9	6.6 ± 1.2	1.5 ± 1.2	5.4 ± 0.9	8.3 ± 1.1	7 with CSF leak, 4 with wound infection and 1 requiring irrigation and debridement, 1 with delayed wound healing, 4 with hyperalgesia of lower limbs

VAS: visual analog scale; mJOA: modified Japanese Orthopaedic Association; CSF: cerebrospinal fluid.

**Table 4.** Table listing the various advantages and disadvantages of the biportal endoscopic technique for cervical and thoracic spine surgery

Advantages	Ultra minimally invasive
	Improved pain and recovery from reduced soft tissue dissection
	Enhanced visualization of spinal anatomy
	May avoid fusion by preserving bony anatomy
Disadvantages	Risk of spinal cord injury
	Difficulty in treating diffuse, multilevel pathology
	High level of difficulty with steep learning curve
	Only for use in highly select cases

racic central stenosis is limited by the increased risk of spinal cord injury, especially since the spinal cord is already compromised from the stenosis. Significant care should be taken with introducing surgical instruments into the endoscopic field. An important balance should be made with the inflow and outflow of the endoscopic fluid and particular attention should be paid to the status of the inflow and outflow throughout biportal endoscopic surgery. On one hand, the hydrostatic pressure of the endoscopic fluid can reduce bleeding in the epidural space by gently compressing the epidural veins and maintain a clear visual endoscopic field. On the other hand, excessive epidural pressure into the spinal canal can cause iatrogenic spinal cord compression if there is high inflow or insufficient outflow of endoscopic fluid. Many authors recommend keeping the irrigation fluid pressure below 30 mmHg for this very reason.

There is some concern of thermal injury to the neurological structures with the radiofrequency probe and the radiofrequency generator should be set at the lowest setting. Extreme care should be placed on bringing the radiofrequency probe too close to the dura and spinal cord. Utilizing small hook tip radiofrequency probes can precisely deliver the hemostatic energy to a very specific location of the epidural veins, which may reduce the risk of thermal injury to the surrounding neurological structures. Although this is a theoretical risk, no case reports or complications have been described in the published literature to date. Hydrostatic agents such as gelfoam powder soaked in thrombin, Floseal hemostatic matrix, etc can aid in the hemostasis of the epidural veins within the spinal canal.

Intraoperative neuromonitoring should be utilized for these cases. Post-surgical drains should be employed to remove bleeding that could develop into compressive post-operative epidural hematomas, leading to spinal cord compression and neurological deterioration. Furthermore, the technique should be used in select patients and by surgeons who have mastered the biportal technique in the lumbar spine. Traditional open techniques should be the mainstay of treatment until the safety

and clinical effectiveness of biportal endoscopy is fully demonstrated with well-designed clinical studies.

## POSSIBLE APPLICATIONS

Other uses of biportal endoscopy in the cervical and thoracic spine that have yet to be reported in the literature include evacuation of epidural hematoma and epidural abscess, surgical debridement of osteomyelitis and discitis, surgical decompression of metastatic tumors to the spine, and applications in spine trauma. The treatment of epidural hematoma and epidural abscess with biportal endoscopy would require that the pathology is limited in nature and not diffuse over multiple levels, which would then necessitate open laminectomy and evacuation. Ideally, the lesions are at 1 or 2 levels, localized to the disc space. Computer navigation may assist in localizing the lesions relative to the surrounding more normal spinal anatomy, which can optimize the chances for the success of the surgery.

Kim and Jung [19] published a case report of successfully implementing biportal spinal endoscopy to treat multilevel spontaneous lumbar epidural hematoma but there are no reports of using the technique for cervical and thoracic instances. Biportal endoscopy with intravenous antibiotic therapy was used to successfully treat 13 patients for lumbar epidural abscesses by Kang et al. [20]. Five patients were infected with *Staphylococcus aureus* with 3 of the 5 having the methicillin-resistant strain. Eight patients reported excellent outcomes using the modified Macnab criteria and 5 patients reported good outcomes. There were no instances of recurrence of infection or perioperative complications with full resolution of the infection. Hsu et al. [21] published a case report on treating *Salmonella* spondylodiscitis and epidural abscess that extended from T12 to S1 using biportal discectomy and debridement at the L1-2 and L4-5 levels, then introducing a drainage catheter into the epidural space in the intervening levels. However, no reports have been published to date on the use of biportal endoscopy for treatment of epidural abscess in the cervical or thoracic spine.

Treatment of cervical and thoracic metastatic lesions with biportal endoscopy may be a viable option if there is limited spinal cord compression with more localized tumor that was accessible to the endoscope. Tumors that may be more amenable to biportal endoscopy would be those located dorsally or along the lateral borders of the spinal canal and pedicles rather than circumferentially around the spinal cord. Severe circumferential spinal cord compression should be avoided with this technique. Perhaps the far lateral “cave-in” technique de-

scribed by Jing et al. [18] for thoracic OPLL may be utilized for thoracic metastatic tumors to access the ventral aspect of the spinal canal for mild to moderate circumferential spinal cord decompression. Significant consideration must be made on the vascularity of the tumor since vascularized tumors such as renal cell carcinoma can lead to significant intraoperative bleeding, which would completely obstruct the visualization with the endoscope. Preoperative angiography and embolization may be necessary for certain tumor types to reduce the intraoperative bleeding. Even in tumor types that do not have such vascularity, metastatic tumors can induce a hyperemic state to allow further growth of the tumor. This hyperemic environment can cause enough bleeding intraoperatively to obscure visualization using the biportal endoscopic technique. In addition, the risk of spinal cord injury would still need to be mitigated for biportal endoscopy to be a feasible treatment option. Only highly select cases would be amenable to the biportal technique.

In the trauma setting, utilizing biportal endoscopy for spinal canal decompression in lieu of an open laminectomy may preserve what stability may be left by the traumatized posterior ligamentous complex. Retropulsed fragments in thoracolumbar burst fractures may be reduced in the acute setting using biportal endoscopic visualization. Traumatic epidural hematomas that are limited in size and extent may also be amenable to biportal endoscopy. Although no studies have yet been published on these topics, an opportunity exists to translate the biportal technique to these pathologies in the cervical and thoracic spine.

### Recommendations for Risk Reduction

1. Avoid excessive irrigation fluid pressure by maintaining irrigation pressure < 30 mmHg and ensuring ample outflow.
2. Use particular care when inserting surgical instruments into the endoscopic field.
3. Use specialized small hook tip radiofrequency probes to precisely deliver hemostatic energy to reduce thermal injury to the spinal cord and neurological structures.
4. Use radiofrequency generator at the lowest setting once in the spinal canal.
5. Utilize intraoperative electrophysiological neuromonitoring with somatosensory evoked potentials, motor evoked potentials, and EMG
6. Use post-operative drains for all cases.
7. Perform cervical and thoracic cases only after mastering the biportal endoscopic technique in the lumbar spine in select cases only.

## CONCLUSIONS

Applications of biportal spinal endoscopy has recently progressed from the lumbar spine to the cervical and thoracic spine. To perform the technique safely in the cervical and thoracic spine, surgeons must first master the technique in the lumbar spine, where there is more room for error. The learning curve is steep for biportal endoscopy as it is for full uniportal endoscopy, however the flexibility, adaptability, and maneuverability may be greater in biportal endoscopy due to the separate viewing and working portals. This may allow for the successful use of biportal endoscopy in the cervical and thoracic spine. Due to the risk of spinal cord injury in the cervical and thoracic spine, measures should be implemented to reduce this risk, such as proper irrigation fluid management, proper insertion and manipulation of surgical instruments to the endoscopic field, meticulous hemostatic technique, intraoperative neuromonitoring, and postoperative drain management. By first mastering the biportal technique with posterior cervical laminoforaminotomy for cervical disc herniations and foraminal stenosis, surgeons can then gradually progress to spinal cord decompression in the cervical and thoracic spine as their skills advance. More extensive research is necessary with well-designed comparative studies with long term follow-up to determine the factors necessary for the safe and effective use of the biportal endoscopic technique in the cervical and thoracic spine. The biportal endoscopic technique is a viable alternative to full endoscopy and other minimally invasive techniques, now with applications in the cervical and thoracic spine.

## NOTES

### Ethical statements

Not applicable.

### Conflicts of interest

Dong Hwa Heo is the Editor of the Journal of Minimally Invasive Spine Surgery and Technique and was not involved in the review process of this article. All authors have no other potential conflicts of interest to declare relevant to this article.

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# Contralateral Inside-out Biportal Endoscopic Posterior Cervical Foraminotomy: Surgical Techniques and Preliminary Clinical Outcomes

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**Objective:** The aim of this study was to describe the surgical techniques and preliminary results of inside-out biportal endoscopic posterior cervical foraminotomy (BEPCF) for unilateral cervical radiculopathy.

**Methods:** This study involved 36 consecutive patients (38 segments) who underwent BEPCF for unilateral cervical radiculopathy between November 2020 and June 2022. Foraminotomy was performed using the biportal endoscopic technique, with the surgeon standing on the opposite side and making skin incisions on the same side of the foramen stenosis. After widening of the V-point and exposing the nerve root using a high-speed drill, we used a curved osteotome to undercut the facet joint from inside the foramen to complete the nerve root decompression.

**Results:** The study followed patients for an average of 15.5 months and found significant improvements in the visual analog scale for arm pain, from  $7.3 \pm 2.2$  to  $0.9 \pm 0.7$  ( $P < 0.005$ ), and the Neck Disability Index, from  $54.6 \pm 16.9$  to  $14.6 \pm 12.6$  ( $P < 0.005$ ). Almost all patients (94.4%) had good or excellent results. Hospitalization lasted an average of 3.2 days and postoperative magnetic resonance imaging showed successful neural decompression. Complications were minimal, with only two cases of asymptomatic root abrasions and one case of transient neuralgia. One patient required re-operation due to incomplete decompression.

**Conclusion:** BEPCF is a safe and effective surgical technique for treating cervical radiculopathy. The surgeon can achieve good neural decompression and preserve the facet joint using the inside-out approach in an ergonomic setting.

**Key Words:** minimally invasive surgical procedures, surgical endoscopy, cervical spine, radiculopathy, foraminotomy, treatment outcome

## INTRODUCTION

Cervical radiculopathy typically presents with neck pain, arm pain, paresthesia, numbness, or motor weakness due to inflammation or compression of the cervical nerve root [1,2]. The most common causes of cervical radiculopathy are cervical

disc herniation and cervical spondylosis [3,4]. While anterior cervical discectomy and fusion (ACDF) has been considered the gold standard in managing cervical radiculopathy [5], the literature shows a variety of complications associated with the procedure, including adjacent segmental diseases, pseudoarthrosis, postoperative dysphagia, vascular injury, recurrent



laryngeal nerve palsy, cerebrospinal fluid leakage, and hematoma [6-8].

Traditional posterior cervical foraminotomy (PCF) was developed long before ACDF and is recognized as a simple and effective surgical treatment for cervical radiculopathy [9]. It avoids the complication associated with anterior approach and preserves the mobility of the operated segment [9-11]. However, traditional PCF requires a large surgical incision and massive dissection of the posterior neck musculo-ligamentous structures. The extensive soft tissue damage resulting from this approach may lead to severe wound pain, delayed recovery, and a high incidence of postoperative neck pain [9,12,13]. In addition, excessive facet joint destruction may lead to the concerns for post-decompression segmental instability which requires a second operation for reconstruction [14,15].

In recent years, spine surgeons have paid attention to the biportal endoscopic technique. This technique is performed through two independent portals with continuous irrigation of normal saline, providing hydrostatic pressure to suppress bleeding and carry away bone debris and oozing. Combined with a high-resolution endoscope, the biportal endoscopic technique provides a clear, bright, and magnified surgical field of view, enabling surgeons to perform delicate surgical procedures without excessive soft tissue damage. This minimally invasive technique has been applied to address a variety of spinal pathologies, such as discectomy for lumbar disc herniation, laminotomy for degenerative lumbar spinal stenosis, and lumbar interbody fusion for disc degeneration or spondylolisthesis, all of which have demonstrated good clinical efficacy [16-21].

Recently, we have performed biportal endoscopic posterior cervical foraminotomy (BEPCF) in patients with unilateral cervical radiculopathy, attempting to make traditional PCF a minimally invasive procedure. The purposes of the study are to describe the surgical techniques in detail, and to evaluate the preliminary clinical outcomes.

## MATERIALS AND METHODS

### 1. Patient Selection

This case series included 36 consecutive patients who received 38 segments of biportal endoscopic posterior cervical foraminotomy (BEPCF) between November 2020 and June 2022. The patients were 24 males and 12 females with an average age of 56.8 years (range 39–63 years).

Indications for BEPCF were radicular arm pain, single or multiple cervical radiculopathies due to foraminal stenosis,

with persistent symptoms for more than three months and failure of conservative treatment. We excluded patients with segmental instability, kyphotic sagittal alignment, and prior surgeries in their cervical spines. Patients with central canal stenosis and myelopathy, characterized by abnormally increased deep tendon reflexes, hyperclonus of ankles, abnormal Babinski reflexes, or gait disturbance were also excluded. Thirty-four patients received one-segment decompression, while two patients received two-segment decompression (Table 1). All surgeries were performed by the senior author in a single medical center.

### 2. Evaluation of Clinical Data and Outcomes

We obtained demographic and clinical data, as well as treatment outcomes, through chart reviews. All patients underwent baseline evaluation before surgery, followed by evaluations at 1 month, 3 months, 6 months, and 1 year after surgery, and then annually thereafter. Outcome measures included the visual analog scale (VAS) for arm pain, the neck disability index (NDI) for disability [22], and the modified MacNab criteria for the overall outcomes [23].

All patients underwent plain X-rays of AP, lateral, oblique, and dynamic lateral views before the surgery, as well as at 3 months, 6 months, and 1 year after the surgery. Additionally, all patients received a cervical spine magnetic resonance im-

**Table 1.** Demographic data and clinical characteristics

Patients	36
Sex	
Male	24 (66.7%)
Female	12 (33.3%)
Age, yr (range)	56.8 (39–63)
Diagnosis	
Foraminal stenosis	32 (88.9%)
Disc herniation	4 (11.1%)
Segments of decompression	
One-segment decompression	34 (94.4%)
Two-segment decompression	2 (5.6%)
Total segments	38
C4–5	5 (13.1%)
C5–6	18 (47.4%)
C6–7	15 (39.5%)
Follow-up, mo (range)	15.5 (6–31)
Hospital stays, d (range)	3.2 ± 1.2 (2–6)
Operation time, min (range)	58.4 ± 15.4 (42–90)
Complications	
Nerve root injury	2 (5.6%)
Transient neuralgia	1 (2.8%)
Incomplete decompression	1 (2.8%)

aging (MRI) study prior to the surgery. The MRI study included T1-weighted and T2-weighted images with 3mm thin slices at sagittal, axial, coronal, and oblique sagittal planes perpendicular to the neuroforamen for evaluation. Post-operative MRI studies were performed at 3 months after the surgery. To evaluate facet preservation, we compared the pre-operative and post-operative axial MRI images using the method described by Matsumura et al. [24] and Dohzono et al. [25]. However, MRI was used instead of CT scan.

The independent t-test was used to compare continuous variables between groups, while the chi-square test was used to compare categorical variables. A p-value of <0.05 was considered statistically significant.

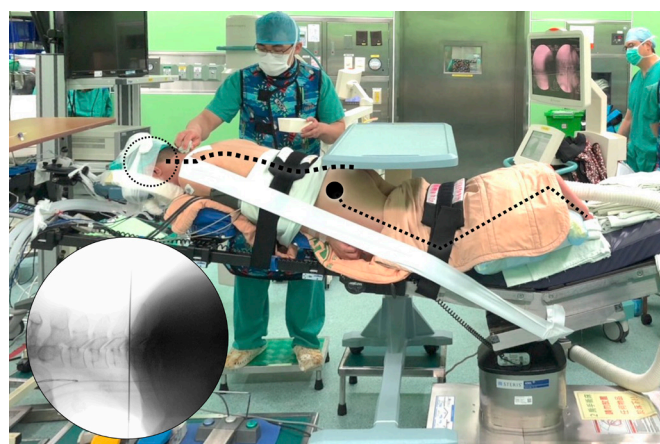
### 3. Surgical Techniques

BEPCF is performed under endotracheal general anesthesia with the patient placed in a prone position on a radiolucent surgical table with his/her head supported by the headrest. The table must be adjusted to ensure free passage of the fluoroscope to obtain clear anteroposterior and lateral images. The patient's shoulders are retracted caudally and fixed on the surgical table using adhesive tapes. The table can be tilted head-up or head-down to keep the segment of interest perpendicular to the floor for precise localization and more ergonomic handling of the endoscope and surgical instruments (Figure 1). Since the surgery is performed with continuous saline irrigation, a watertight draping is essential to prevent soaking and resultant hypothermia of the patient.

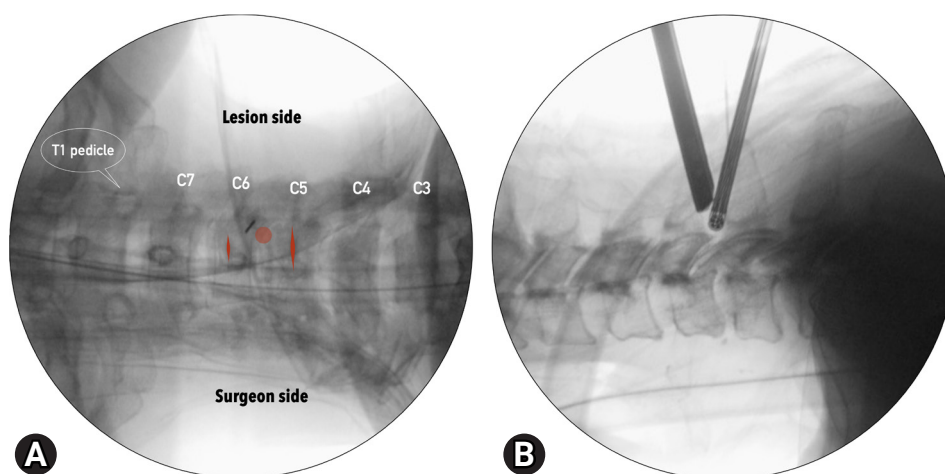
First, we determine the disc level of interest using the lateral

fluoroscopic image. Then, using the anteroposterior images, we draw the skin markings. The V-point (junction of cranial and caudal laminae) must be clearly identified as the initial target for landing the endoscope and surgical instruments. For the contralateral inside-out approach, taking the left side foraminotomy for example, the surgeon stands on the patient's right side, and the skin incisions are along the left lateral border of the spinous processes, separated by about 2 cm (Figure 2). For a two-segment decompression, a wider separation is needed.

We prefer transverse skin incisions for better cosmetic results. The deep neck fascia is tough and requires a sharp No. 11 scalpel for penetration. Then, we use a blunt dilator to palpate the margins of the laminae around the V-point. The endoscope (4



**Figure 1.** Patient positioning. The surgical table is adjusted so that the target disc level is perpendicular to the floor. The result is confirmed using a fluoroscope.

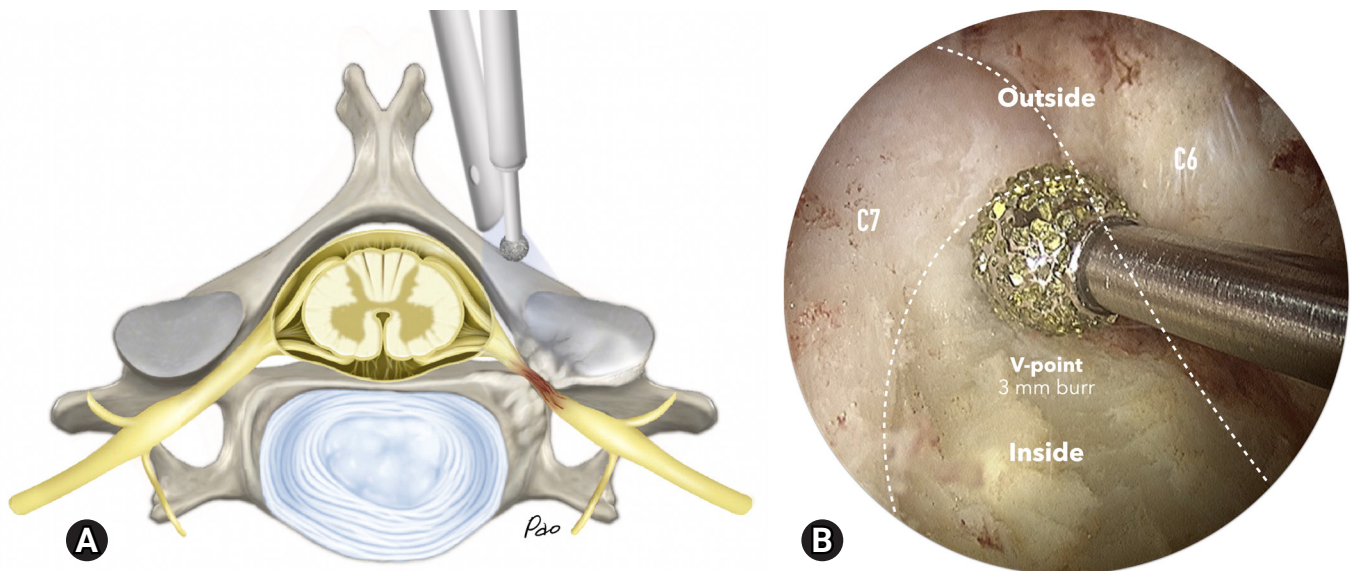


**Figure 2.** Skin marking and triangulation. (A) The V-point (red dot) is identified on antero-posterior images. Transverse skin incisions (red lines) should be made along the lateral border of spinous processes, separated by approximately 2 cm. (B) The level and triangulation are confirmed on lateral images.

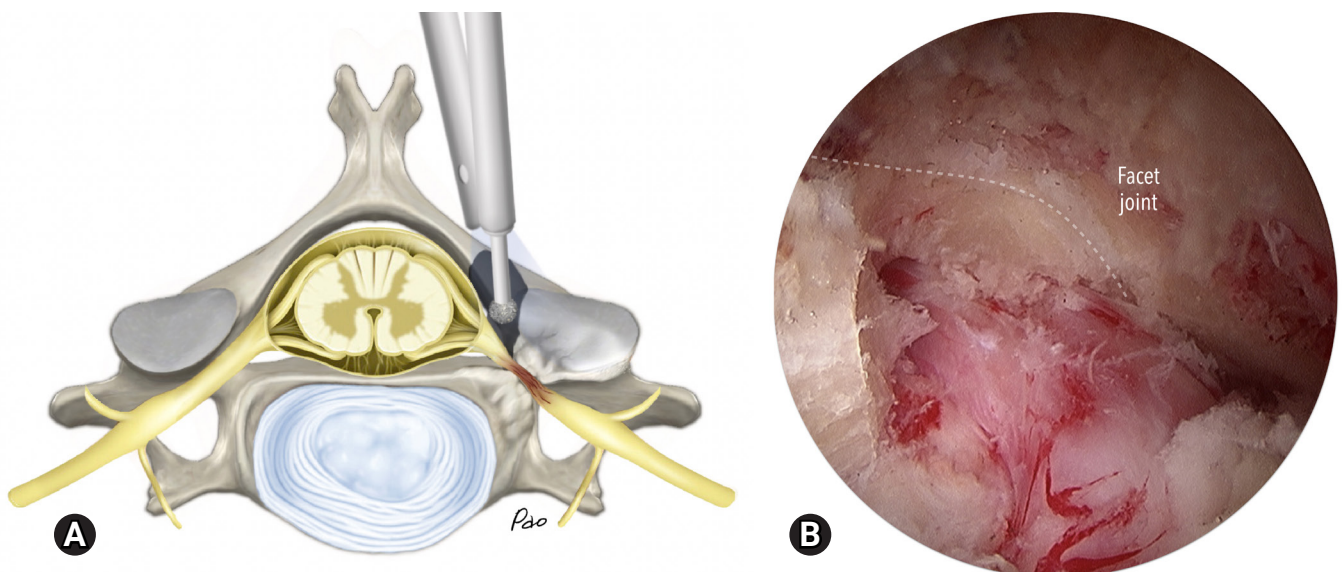
mm  $\times$  30°; ConMed, Largo, Florida) and radiofrequency wand (ArthroCare, Austin, Texas) are inserted through independent skin incisions with inflow of normal saline. The triangulation formed by the endoscope, V-point, and radiofrequency wand must be confirmed under the fluoroscope (Figure 2). Use the radiofrequency wand to ablate the soft tissue to identify the V-point and create the working space required for the following procedures (Figure 3). Good control of saline inflow/outflow

is mandatory to maintain a clear surgical field while using the high-speed drilling system.

Starting from the V-point, extend the foraminotomy cranially, caudally, and laterally until the margin of the ligamentum flavum is exposed (Figure 4). A high-speed drill with a 3-mm coarse diamond ball tip (Primado II; NSK, Tokyo, Japan) is used as the primary instrument for removing bone. Use the nerve hook to elevate the ligamentum flavum and the under-



**Figure 3.** (A) This illustration demonstrates the foraminal stenosis caused by osteophytes that arise from the uncovertebral joint and hypertrophy of the facet joint. (B) An endoscopic photo shows the V-point viewed in the inside-out approach.



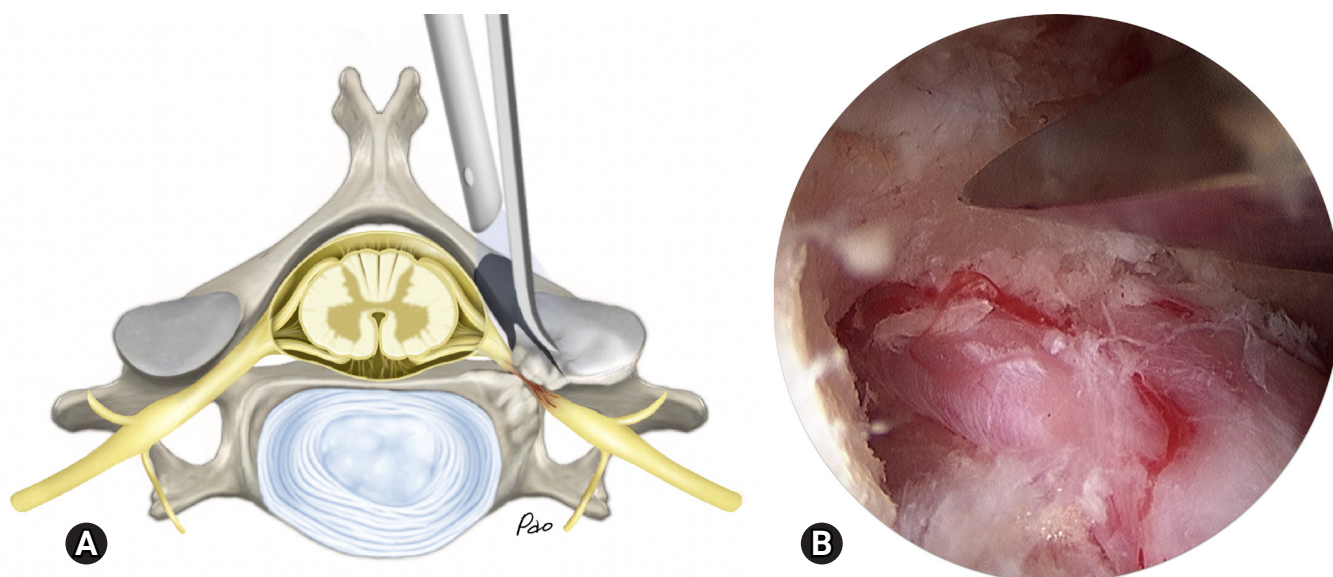
**Figure 4.** (A) An illustration demonstrates foraminotomy, which uses a high-speed drill to expose the nerve root. (B) An endoscopic photo shows the facet joint (dashed line) and impingement of the nerve root in the neural foramen.



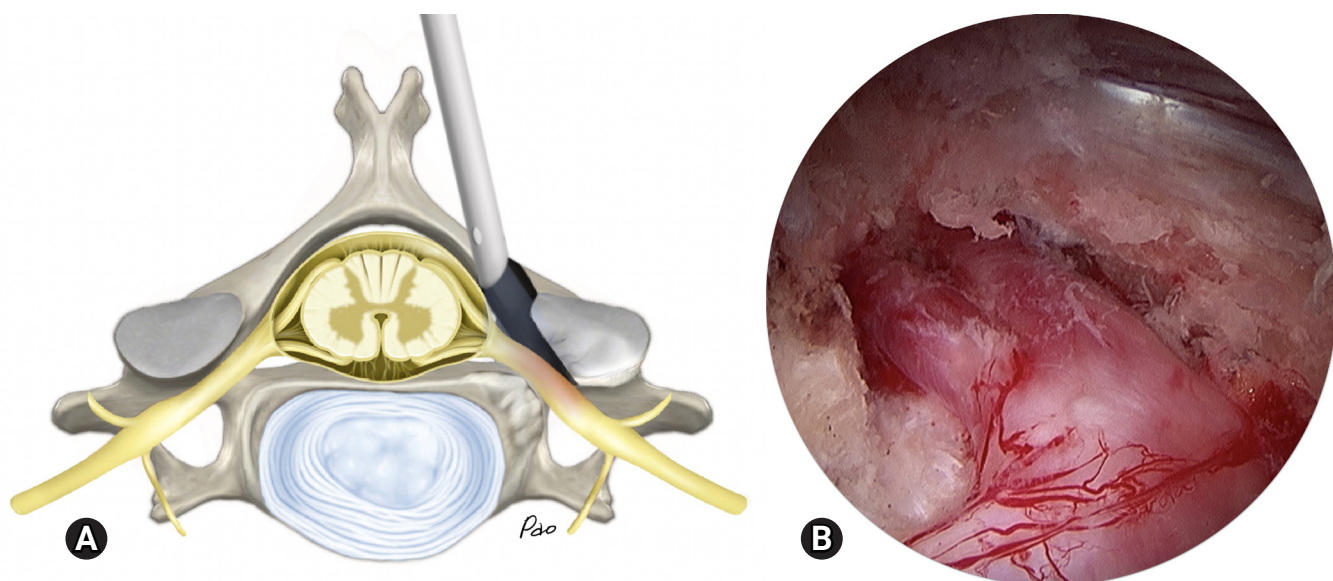
lying perineural membrane, removing only the portion of the ligamentum flavum which covers the nerve root. Coagulate the bleeders on the perineural membrane or epidural vessels using a 0.8 mm radiofrequency wand, and identify the nerve root. Use a 3-mm wide curved osteotome to undercut the cranial and caudal laminae to identify the inner surface of the pedicles. Then, use the same osteotome to undercut the superior articular process of the caudal vertebra (Figure 5). Use a small, angled curette to remove the bony fragments and free the nerve

root. Check the adequacy of decompression and mobility of the nerve root using a nerve hook (Figure 6). Temporarily stop the irrigation to check the pulsation of the nerve root and identify the active bleeders. Use the radiofrequency wand to coagulate the bleeders and bone wax to seal the cancellous bone. Close the wounds by layers, using absorbable sutures to close the skin incisions and adhesive gel to secure them.

To control wound pain, the patient is given oral acetaminophen and intravenous morphine. They are allowed to ambulate



**Figure 5.** An illustration (A) and an endoscopic photo (B) demonstrate the use of a curved osteotome to undercut the facet joint and decompress the nerve root.



**Figure 6.** An illustration (A) and an endoscopic photo (B) demonstrate complete decompression of the nerve root between the cranial and caudal pedicles.

with a soft neck collar. Typically, the patient is discharged from the hospital on the second postoperative day.

RESULTS

The average follow-up period was 15.5 months, ranging from 6 to 31 months. The average duration of hospitalization was 3.2±1.2 days, ranging from 2 to 6 days. The mean operation time was 58.4±15.4 minutes per segment of decompression (Table 1). Most patients experienced minimal pain at the surgical sites, and pain control with oral acetaminophen was usually sufficient. Only a few patients required one or two doses of morphine infusion. At the final follow-up, the VAS score for arm pain significantly improved from 7.3±2.2 to 0.9±0.7. The NDI also improved from 54.6±16.9 to 14.6±12.6. All these improvements were statistically significant from the baseline with p<0.005. According to the modified MacNab criteria, 21 patients (58.3%) had excellent results, 13 patients (36.1%) had good results, 2 patients (5.6%) had fair results, and no patient had poor results. The ratio of good and excellent results was 94.4% (Table 2).

All patients underwent regular X-ray evaluations at 3, 6, and 12 months after surgery. We did not observe post-decompression segmental instability in any of our patients. Post-operative MRI follow-up at 3 months after surgery showed adequate decompression and enlargement of the neural foramen at the oblique sagittal plane with minimal facet joint destruction and soft tissue injury (Figure 7, 8). Post-operative MRI data were available for 22 patients, and the average facet preservation rate was 81.7%±8.0%, ranging from 64.5% to 91.5% (Figure 9).

Complications included two asymptomatic root abrasions and one case of transient neuralgia. There were no cases of dural tear or neurological complications. In the very early series, one patient experienced persistent radicular symptoms due to incomplete decompression. To alleviate his symptoms, a revision BEPCF procedure was performed (Table 1).

DISCUSSION

This study presents a minimally invasive surgical technique for treating cervical radiculopathy using the biportal endoscopic technique. The treatment resulted in good clinical outcomes, including significant improvement in VAS score and ODI, a short hospital stay, and a low complication rate. The contralateral inside-out approach provides adequate nerve root decompression with minimal facet joint destruction and soft tissue injury, while also offering ergonomic settings for the surgeon to perform the surgery.

The estimated annual incidence of cervical radiculopathy is 85 out of 100,000 people, and it usually occurs at the C5/6 and C6/7 levels [2,3]. The most common clinical presentations are radicular arm pain, followed by sensory deficit, neck pain, and reflex deficit [26]. Non-operative management, including medication, programmed rehabilitation, and epidural steroid injection, has been proven to achieve significant symptom relief in 75% to 90% of these patients [3,27]. However, for those who experience intolerable and persistent symptoms after conservative treatment, surgical decompression may be a good alternative solution. There are two mainstreams of surgical treatment: ACDF from an anterior approach, and PCF from a posterior approach [5,28].

ACDF removes the entire disc, restores disc height and lordotic alignment, and reconstructs segmental stability without damaging the posterior neck muscles. It is considered the gold standard surgical treatment for cervical radiculopathy due to its ability to provide quick and effective relief for neck pain, arm pain, and neurological symptoms [5,11,29]. However, there are many disadvantages associated with spinal fusion and the anterior approach that are also well documented in the literature [6-8].

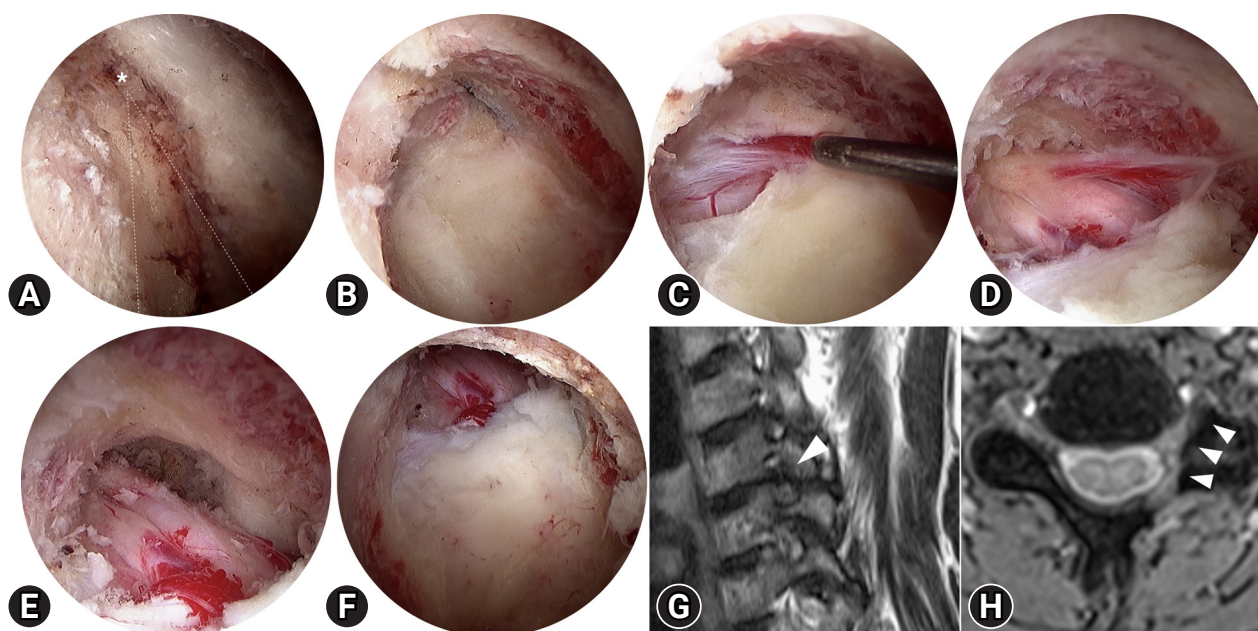
In contrast, PCF decompresses the nerve roots directly via a posterior approach, avoiding the complications associated with an anterior approach. Several studies have shown that PCF pro-

Table 2. Clinical outcomes for 36 patients

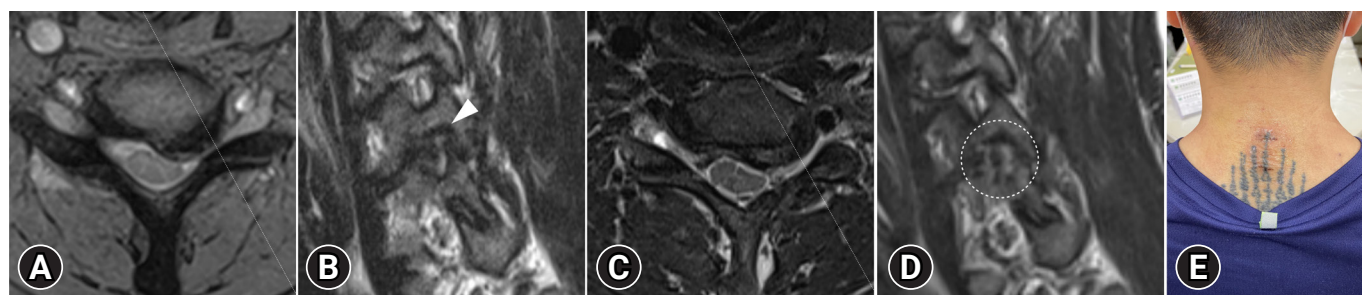
	Pre-operative	Post-operative	p-value
VAS for arm pain	7.3 ± 2.2	0.9 ± 0.7	< 0.005
NDI	54.6 ± 16.9	14.6 ± 12.6	< 0.005
Modified MacNab criteria (%)			
Excellent		21 (58.3%)	
Good		13 (36.1%)	
Fair		2 (5.6%)	
Poor		0	

VAS: visual analog scale, NDI: neck disability index.





**Figure 7.** A series of endoscopic photos shows a 62-year-old woman with left-side C5-6 foraminal stenosis. (A) The initial V-point (white asterisk). (B) Foraminotomy. (C) Elevation of the ligamentum flavum. (D) Removal of the perineural membrane. (E) Complete decompression of the nerve root viewed from inside of the foramen. (F) The extent of foraminotomy viewed posteriorly. Most of the ligamentum flavum is preserved. (G) A preoperative oblique sagittal magnetic resonance image shows the foraminal stenosis (white arrowhead). (H) A postoperative axial magnetic resonance image shows widening of the foramen with minimal destruction of the facet joint (white arrowheads).

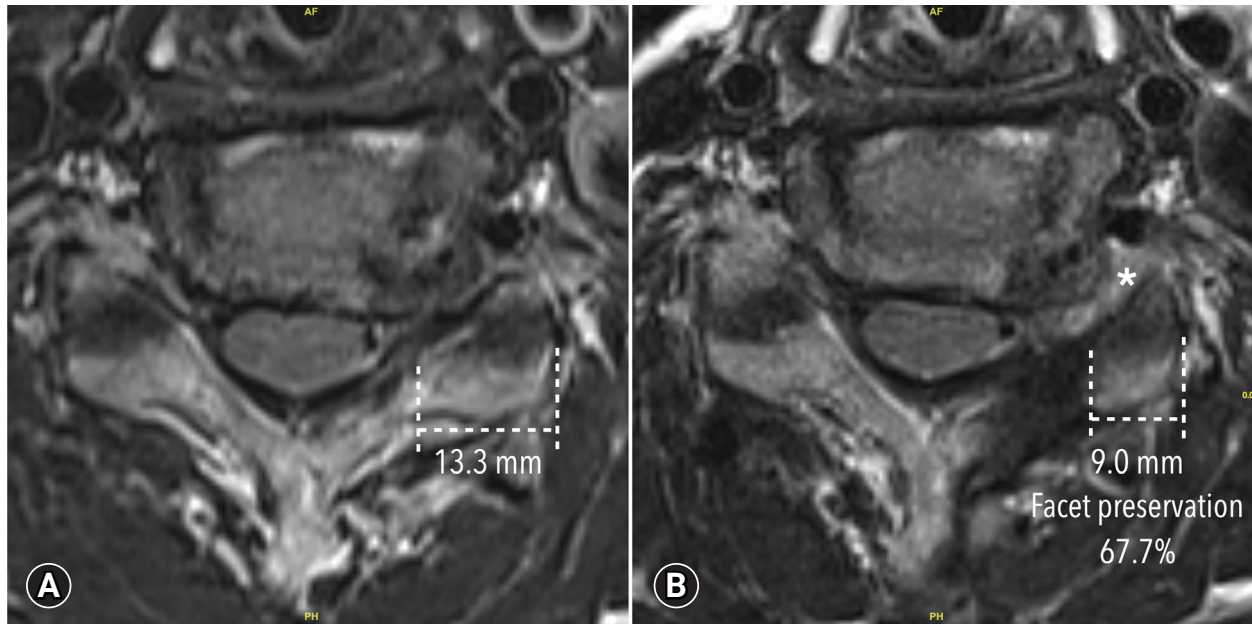


**Figure 8.** Preoperative magnetic resonance images (A, B) reveal left-side foraminal stenosis (white arrowhead), caused by osteophytes originating from the uncovertebral joint in a 57-year-old male patient. (C, D) Postoperative magnetic resonance images demonstrate good decompression of the neural foramen (indicated by the white dashed circle). (E) A clinical photograph displays the cosmetic surgical wounds.

vides comparable clinical outcomes in terms of symptom relief, complication rate, and patient satisfaction compared to ACDF, while preserving the range of motion of the cervical spine and avoiding adjacent segment degeneration [3,9,10]. A systematic review conducted by Liu et al. [11] summarizes that there was no significant difference in the complication rate and reoperation rate between ACDF and PCF within 2 years of the initial surgery. A meta-analysis conducted by Fang et al. [5] concludes that PCF is a sufficient alternative to ACDF with shorter operation time, shorter length of hospital stays, and a lower total

hospital cost. However, the major drawbacks of traditional PCF are excessive damage to the posterior cervical musculo-ligamentous structures and destruction of the facet joints that contribute to segmental hypermobility and postoperative kyphosis [12,30,31].

To minimize soft tissue damage in open surgeries, a minimally invasive approach using the tubular retractor has been adopted since Dr. Foley and Smith [32] introduced the concept of microendoscopic surgeries in 1997 [33,34]. The microendoscopic PCF shares the advantages of traditional PCF but min-



**Figure 9.** (A) An axial magnetic resonance image taken before the operation shows stenosis in the left foramen. (B) An axial magnetic resonance image taken after the operation shows good decompression of the foramen (white asterisk) with 67.7% facet preservation.

imizes iatrogenic damage and has been reported to provide comparable results in clinical outcomes [28,35,36]. However, handling surgical instruments to perform delicate procedures in such a small tubular retractor is challenging. Even with the assistance of a specially designed endoscope or microscope, it still requires a steep learning curve to achieve stable treatment results and reduce the possibility of neurological complications [37].

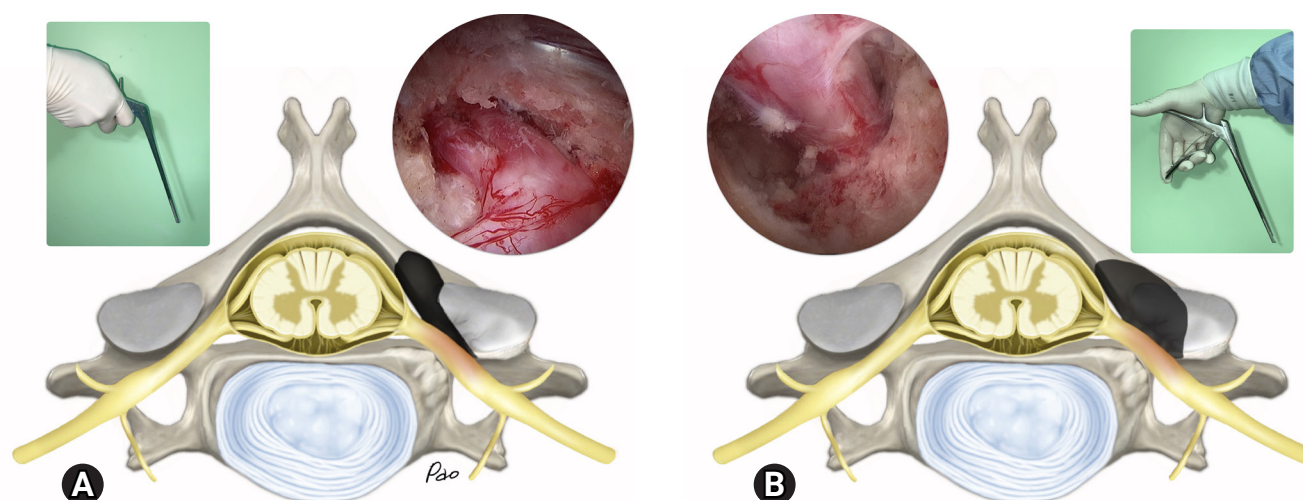
In this study, we introduce a contralateral inside-out PCF technique using biportal endoscopy to treat cervical radiculopathy. Compared to traditional microscopic or microendoscopic PCF, the biportal endoscopic approach results in an almost bloodless surgical field. Normal saline is used to provide hydrostatic pressure to suppress bleeding and carry away bone debris. Although the working space may be small, a high-resolution 30-degree endoscope provides a clear, bright, wide, and magnified surgical field of view [38-40]. The operator and assistants perform the procedure on a video monitor, eliminating the need to bend their necks or strain their eyes on a microscope. The operator holds the endoscope in one hand and surgical instruments in the other, allowing for a relaxed neck and shoulder posture and minimizing the risk of neurological complications during delicate surgical procedures.

Biportal endoscopic surgery has been successfully used to treat a variety of degenerative conditions in the lumbar spine [16-21]. Several studies have shown that the clinical outcomes

of biportal endoscopic surgeries are comparable to those of microscopic or microendoscopic approaches [41-44]. A comparative study of three types of minimally invasive decompressive surgery in patients with lumbar spinal stenosis was conducted by Heo et al. [41]. The study showed that the endoscopy groups, either uniportal or biportal, had better clinical outcomes in the immediate postoperative period than the microscopy group. The better outcomes were possibly due to less soft tissue injury related to surgery in the endoscopy group [41]. Our study also showed that BEPCF is very effective in relieving preoperative arm pain and neurological symptoms, with minimal pain from the surgical sites.

The contralateral inside-out approach differs significantly from the ipsilateral approach (Figure 10). Although the decompression of the nerve root may be equally effective with both approaches, the extent of laminotomy required to achieve an effective decompression is much smaller with the contralateral inside-out approach. Consequently, there is less facet joint destruction. By undercutting the superior articular process, the contralateral inside-out approach may preserve a greater proportion of the facet joint and capsule [45,46]. Therefore, the contralateral inside-out approach may reduce the risk of post-decompression segmental instability or progressive kyphosis after the surgery [14,15]. However, this theoretical advantage requires a long-term follow-up study to validate.

Handling of the endoscope and surgical instruments is more



**Figure 10.** Comparison of the contralateral inside-out (A) and ipsilateral (B) foraminotomy in terms of the extent of facet joint destruction (shaded areas), the viewing angles under the endoscope, and the ergonomics of using the surgical instruments.

ergonomic for the contralateral inside-out approach. With the surgeon positioned on the contralateral side, the endoscopic viewpoint naturally follows the direction of the nerve root from its origin to beyond the foramen. Additionally, handling surgical instruments aligns with the natural posture of the hand. Conversely, the ipsilateral approach presents the endoscopic viewpoint from the opposite side, forcing the surgeon to handle surgical instruments in a non-ergonomic, reversed manner.

The current study has several limitations. First, it is a retrospective study with a small sample size and short-term follow-up. Second, all surgeries were performed by a single spine surgeon who is experienced in minimally invasive and endoscopic spine surgeries. The treatment results and complications may differ if surgeries are performed by another surgeon with a different level of experience. Third, long-term or comparative studies are needed to verify the theoretical or proposed advantages of the contralateral inside-out BEPCF.

## CONCLUSION

BEPCF is a simple, effective, and safe minimally invasive surgical technique for treating unilateral cervical radiculopathy. With appropriate patient selection, spinal fusions and their associated negative consequences can be avoided. When BEPCF is done via the contralateral inside-out approach, the surgeon can perform an effective decompression in an ergonomic setting while preserving the facet joint.

## NOTES

### Ethical statements

The study was approved by the institutional review board of Far Eastern Memorial Hospital (109154-E). The informed consent was waived for the retrospective study design of this study.

### Conflicts of interest

Jwo-Luen Pao is the Editor of the Journal of Minimally Invasive Spine Surgery and Technique and was not involved in the review process of this article. All authors have no other potential conflicts of interest to declare relevant to this article.

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# Minimally Invasive Surgical Technique through a Natural Anatomical Corridor for C1-C2 Screw Fixation

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**Objective:** The atlantoaxial complex exhibits unique morphological and biomechanical characteristics. Trauma, tumors, and inflammatory or congenital diseases may compromise the stability of this joint. The purpose of this study was to describe a minimally invasive surgical (MIS) technique for C1-C2 fixation through an anatomical corridor and to analyze the clinical, surgical, and fusion outcomes using this approach over a 15-year period.

**Methods:** We present a MIS technique utilizing a natural anatomical corridor for C1-C2 screw fixation, which has been used at our institution since 2007. We analyzed the demographic characteristics and clinical results of the patients who underwent this procedure.

**Results:** Forty-seven patients underwent C1-C2 MIS screw fixation during the study period, with 24 male patients and a median age of 66 years. The indication for surgery was atlantoaxial subluxation in 60% of cases and odontoid fracture in 23%. The median surgery duration was 130 minutes, with a median blood loss of 300 mL. There were no intraoperative complications, and only one patient presented with a superficial wound infection, which was successfully treated with antibiotics.

**Conclusion:** The minimally invasive approach through a natural anatomical corridor to fuse the atlantoaxial joint using C1 lateral masses and C2 pedicle screws bilaterally has been demonstrated to be safe and effective. Preserving the occipital-cervical tension band provides additional biomechanical stability to the construct.

**Key Words:** Cervical spine, Cervical vertebrae, Fracture fixation

## INTRODUCTION

The atlantoaxial segment is a complex junction with unique morphological and biomechanical features, which play a critical role in the stability of the upper cervical spine. More than half of the head's rotational movement is attributed to this joint [1]. When affected by trauma, tumors, inflammatory or congenital diseases, the stability of this joint may be compromised,

leading to potential neurological consequences. Over the years, various posterior fixation techniques have been developed to stabilize the first and second vertebrae of the upper cervical spine [2,3]. Fixation techniques using C2 pedicle screws and C1 lateral mass screws with plates or rods on each side, or trans articular C1-C2 screw fixation, have shown high fusion rates [4-7].

Percutaneous screw fixation using imaging navigation is a minimally invasive surgical technique for the posterior cervical

spine, but its application may be limited due to the availability of navigation technology, especially in low- and middle-income countries. To address this issue, since 2007, we have developed a minimally invasive trans-muscular approach for the placement of C2 pedicle screws and C1 lateral mass screws in patients with craniocervical junction pathologies, with promising outcomes [8,9]. This technique provides a safe and effective alternative for patients who require surgical intervention for atlantoaxial instability.

To preserve the occipital-cervical tension band, we have described a minimally invasive surgical technique for C1-C2 screw fixation using a natural anatomical corridor found 2 cm away from the midline and parallel to C2 spinous process, as shown in Figure 1A. This corridor is created by the angle between the posterior major rectus capitis and obliquus capitis inferior muscles and is usually free of vascular and nervous structures until reaching the atlantoaxial joint, where a venous plexus is encountered. The bleeding can be easily controlled with bipolar coagulation and absorbable hemostatic agents. In our microsurgical laboratory, we conducted anatomical dissection studies to identify this corridor and its relationship with the vertebral artery for the screw insertion point as shown in Figure 1B [9-11].

The aim of this study is to describe the use of this minimally invasive surgical technique for C1-C2 screw fixation through the anatomical corridor and analyze the clinical, surgical, and fusion results obtained in a 15-year period. This approach has shown to be safe and effective for patients with craniocervical

junction pathologies and can provide an alternative to more invasive surgical techniques while preserving the occipital-cervical tension band.

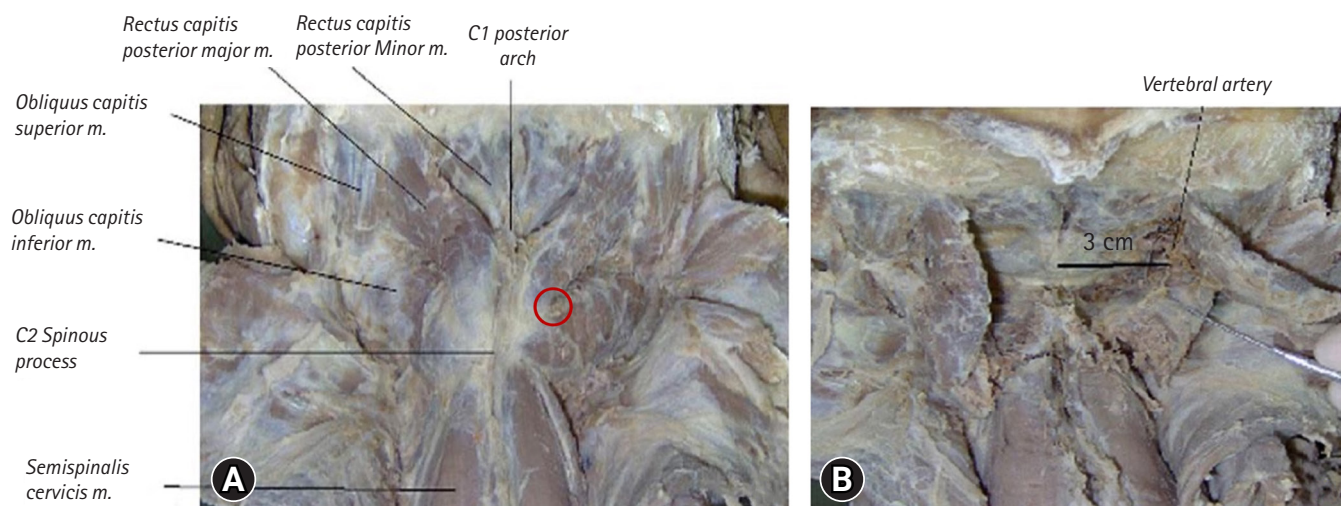
## MATERIALS AND METHODS

### 1. Study Population

The study was conducted at Hospital Universitario San Ignacio in Bogotá, Colombia, and utilized the hospital's Neurosurgery Department databases to collect all data. Medical information from patients who underwent MIS C1-C2 screw fixation between December 2007 and December 2022 was retrospectively evaluated after receiving approval from the institutional review board. All MIS treatments were performed by two spine surgeons with experience in a variety of MIS spinal procedures.

### 2. Data Collection

Baseline patient data, including age, sex, and prior medical histories, were obtained. Operative notes were reviewed to gather information about the type of surgery, the level of pain prior to and after surgery as measured by the visual analog scale, the duration of the surgery, and intraoperative hemorrhage volume. Postoperative information, such as the length of hospital stay, clinical assessments, and postoperative x-rays and tomography, were collected to evaluate fusion.



**Figure 1.** (A) Muscle anatomy of the cranio-cervical junction; the trapezius and semispinalis capitis muscles were removed, and an anatomical corridor between the rectus capitis posterior major and obliquus capitis inferior muscles is shown. (B) Vertebral artery relationship 3 cm away from the midline while coursing to reach the C1 posterior arch.

### 3. Statistical Analysis

Statistical analyses were performed using RStudio Desktop Software 2022 Version (Posit). To establish means and standard deviations for the various variables, descriptive statistics were used.

## INDICATIONS

This surgical technique is most beneficial for patients with C1/C2 instability resulting from inflammatory and degenerative atlantoaxial subluxation, traumatic C1/C2 instability (especially C2 dens fractures and transverse ligament disruption), and basilar invagination associated with fixed atlantoaxial dislocation [2,3]. For cases with significant destruction of the lateral masses of C1 and/or C2 pedicles, requirement of instrumentation and/or decompression of the subaxial cervical spine, a high-riding vertebral artery that obstructs C2 pedicle insertion point or screw trajectory, or presence of ponticulus posticus, alternate posterior fixation techniques are recommended [4-7].

### 1. Preoperative Preparation

Prior to surgery, a comprehensive medical history and physical examination are conducted. Preoperative laboratory testing and risk assessment are routine procedures. It is crucial that the patient and their family fully comprehend the objectives of the surgical intervention. A spine panoramic x-ray is essential to evaluate global sagittal balance and cervical sagittal balance. Pre-operative cervical tomography is also necessary to assess osseous structures and vascular relationships, such as the presence of ponticulus posticus, high-riding vertebral artery, and vertebral artery location in relation to C1 and C2.

### 2. Anesthesia and Patient Position

After the induction of general anesthesia, the patient was positioned in a prone position on a standard radiolucent table over spinopelvic rolls to reduce intraabdominal pressure and protect skin pressure zones. Continuous intraoperative neurophysiological monitoring was recorded throughout the procedure to ensure neural integrity. The head was fixed in a neutral position and secured in a Mayfield clamp (Integra, LifeSciences, Cincinnati, Ohio, United States) to preserve cervical sagittal alignment and the horizontal gaze plane (Figure 2A).

#### 1) Skin Marking and Skin Incision

Paramedian vertical posterior skin marks measuring 25 mm were made (Figure 2B) after identifying the C1 lateral masses and C2 pedicles with intraoperative x-ray. A 10-blade was used to make the skin incision, and monopolar cautery was utilized to dissect the fat tissue and aponeurosis.

#### 2) Insertion of Minimally Invasive System

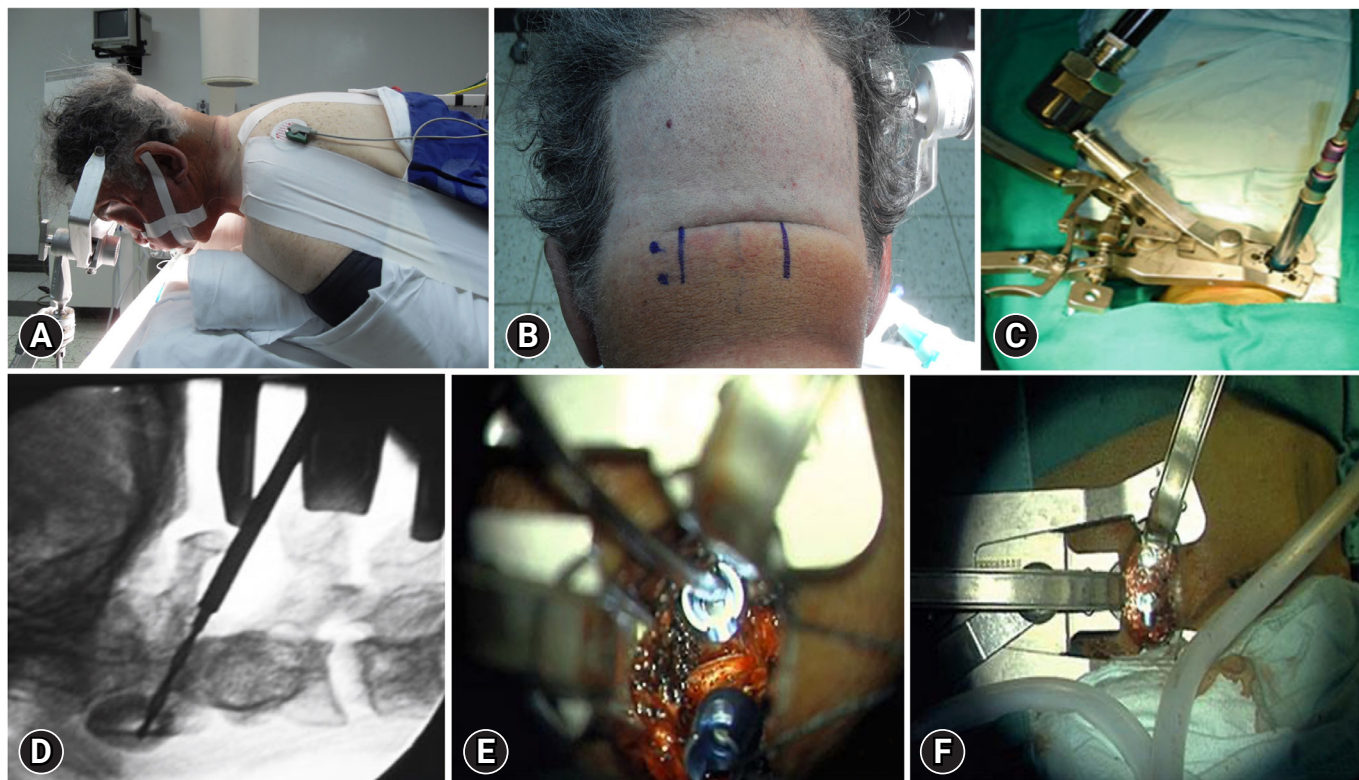
A tubular dilator system platform, microMaXcess® (NuVasive Inc., San Diego, CA, USA), was inserted through the superficial nuchal musculature to access the anatomical corridor between the obliquus capitis inferior and the posterior major rectus capitis muscles (Figure 2C). The proper positioning of the tubular dilator system was verified with intraoperative x-ray in anterior-posterior and lateral projections.

## SURGICAL PROCEDURE

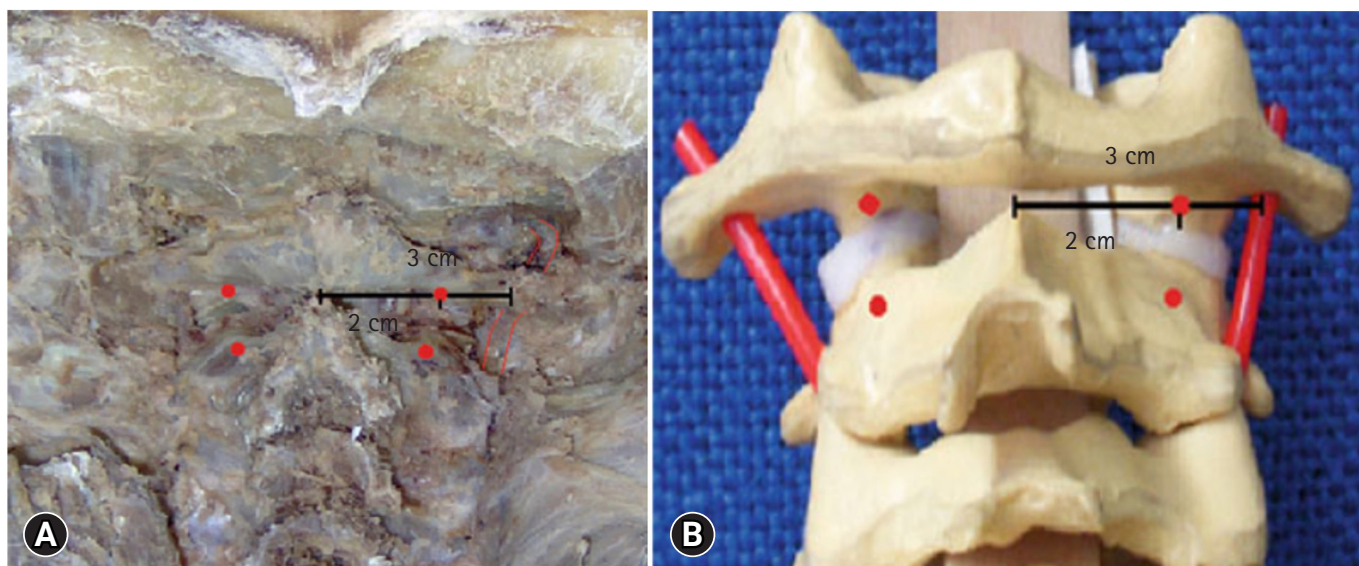
A microMaXcess® MIS tubular dilator system platform (NuVasive Inc., San Diego, CA, USA) was used to perform paramedian vertical posterior skin marks of 25 mm (Figure 2B). Prior to this, the C1 lateral masses and C2 pedicles were identified using intraoperative x-ray. The skin incision was made with a 10-blade, and fat tissue and aponeurosis were dissected with monopolar cautery. The tubular dilator system was then placed through the superficial nuchal musculature to access the anatomical corridor between the obliquus capitis inferior and the posterior major rectus capitis muscles (Figure 2C). Proper positioning of the system was verified with intraoperative x-ray.

A three-valve spreader microMaXcess® with optical fiber light was placed to provide good exposure to the working area. With fluoroscopic guidance, the system was fixed at the entry point of the C2 pedicle without impeding the C1 posterior arch. Adequate positioning of the retractor was verified with anterior-posterior and lateral fluoroscopy. Subperiosteal dissection of the C2 bony surface was performed using monopolar cautery from medial to lateral to expose and fully visualize the lateral border of the C1-C2 joint. During dissection, the epidural venous plexus, which is prone to profuse bleeding, was identified and controlled with bipolar coagulation and standard hemostatic agents. The C2 root was identified, coagulated, and sacrificed to allow screw insertion. The Harms technique was used to for screw insertion with AP and lateral fluoroscopy guidance. Polyaxial screws with a diameter of 3.5 or 4.0 mm were inserted in the C1 lateral mass and C2 pedicles (Figure 2D, E). Figure 3 illustrates the relationship between the screw entry point and vertebral artery trajectory. The articular surface of the C1 and





**Figure 2.** (A) Patient prone with head fixed to a Mayfield clamp. (B) Two paramedian 30-mm skin mark incisions are made. (C) Intraoperative image of the minimally invasive retractor (microMaxcess II®; Nuvasive Inc., San Diego, CA, USA) placed through the anatomical corridor. (D) Intraoperative X-ray during the preparation of the C1 pedicle using the tap. (E) Intraoperative close-up image of the screws through the retractor. (F) Demineralized bone matrix placed within the joint to achieve a second fusion.



**Figure 3.** (A) Entry point of screws using Harm's technique (red points). (B) Relationship of the screws' entry point and vertebral artery trajectory, showing a 1-cm distance between the vertebral artery and the screws' entry point.

C2 joint was decorticated with micro-curettes to place demineralized bone matrix (Grafton® DBM-Putty, Osteotech®, Inc. New Jersey, USA) within the joint to promote fusion (Figure 2F). The same procedure was performed stepwise on the contralateral side. Finally, a standard layered closure was performed using absorbable sutures for muscle and subcutaneous tissue and nylon thread for the skin.

## RESULTS

Forty-seven patients underwent C1-C2 minimally invasive screw fixation surgery during the study period (December 2007– December 2022), using the previously described surgical technique. Of these patients, 24 were male, and the median age was 66 years, ranging from 14 to 88 years old. All patients reported neck pain, with paresthesia being the second most commonly reported symptom (83%). Lower cranial nerve dysfunction was found in only 6 patients. The indication for surgery was atlantoaxial subluxation in 60% of cases and odontoid fracture in 23%. Table 1 summarizes the demographic characteristics of the patients included in the study. Rheumatoid arthritis was the most frequent comorbidity, and most atlantoaxial subluxations were secondary to RA compromise, with 32% of cases being secondary to fractures associated with trauma. Examples of atlantoaxial subluxation and odontoid fracture correction are shown in Figure 4 and 5.

The visual analog scale (VAS) was utilized to evaluate the preoperative pain perception at 30 minutes prior to surgery and three months postoperatively. The median VAS score was 8 before surgery, which improved to 4 at 3 months after surgery.

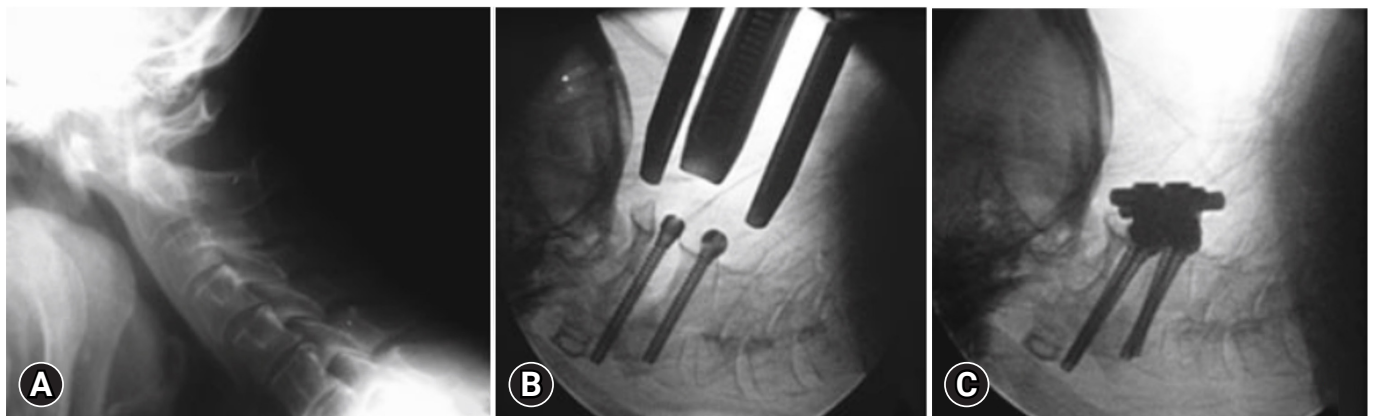
The mean duration of surgery was 130 minutes, with a mean

blood loss of 300 mL (Table 2). Most of the bleeding originated from the venous plexus at the end of the natural anatomical corridor, although it could be appropriately controlled with bipolar coagulation and Gelfoam® (Pfizer Inc., New York, USA). There were no intraoperative complications, and only one patient with uncontrolled diabetes and rheumatoid arthritis suffered a superficial wound infection that was successfully treated with antibiotics, without the need for surgical intervention. The mean follow-up was 4 years (range: 10 years), and osseous fusion of the atlantoaxial joint was achieved in 99% of the patients. No surgical reinterventions were required during the follow-up period.

**Table 1.** Demographic characteristics

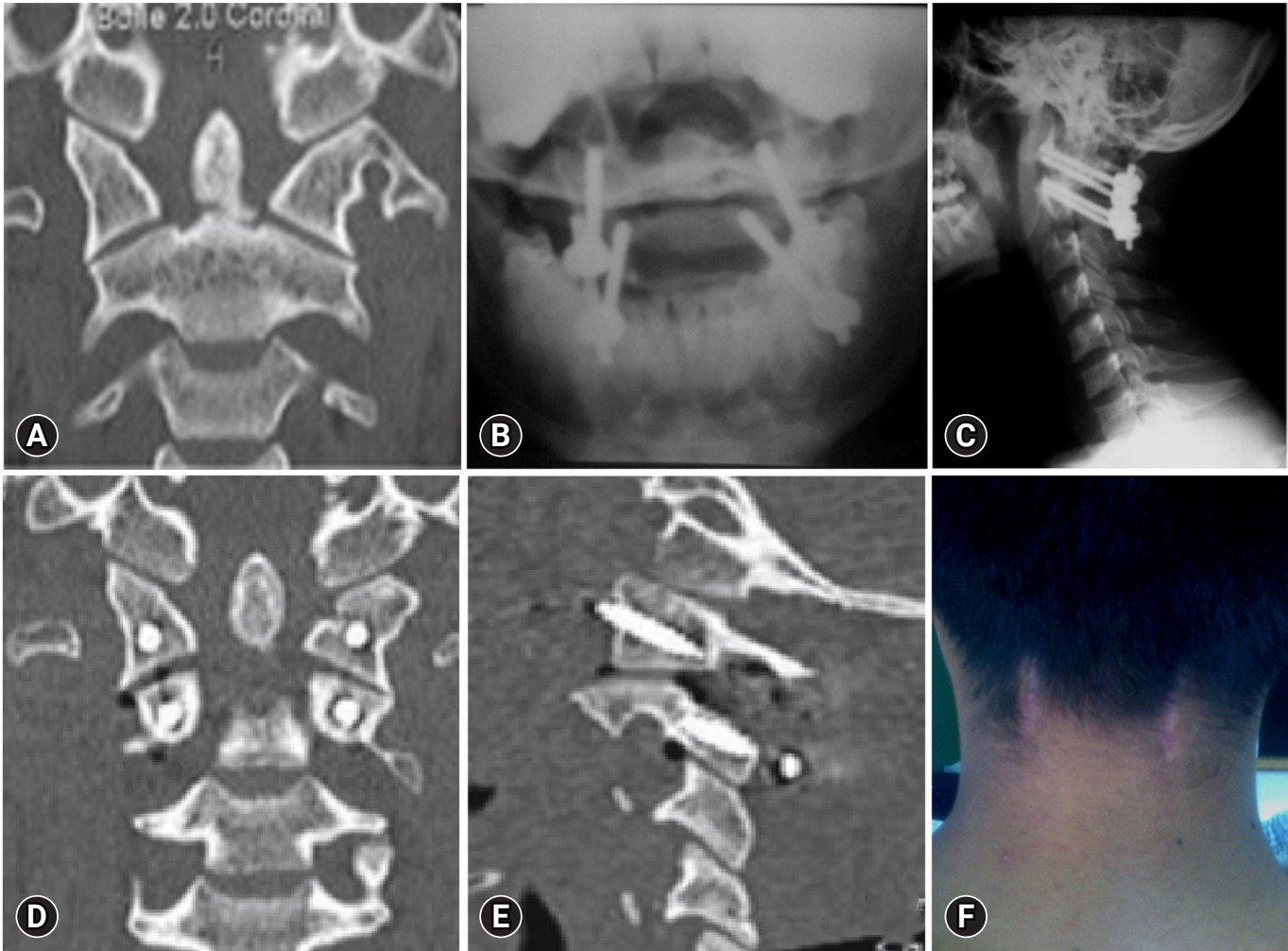
Variables	Value mean (%) median (IQR)
Age (yr)	66 (33)
Sex	
Female	23 (49%)
Clinical presentation	
Neck pain	47 (100%)
Paresthesia	40 (85%)
Weakness	18 (38%)
Lower cranial nerve disturbance	6 (12.5%)
Surgical indication	
Atlantoaxial subluxation	28 (60%)
C1/C2 fractures	
Odontoid fracture	11 (23%)
Jefferson fracture	8 (17%)
Comorbidities	
Rheumatoid arthritis	34 (72%)
Arterial hypertension	15 (32%)
Diabetes mellitus	10 (21%)
Trauma	15 (32%)

IQR: interquartile range.



**Figure 4.** (A) Lateral X-ray image of C1-C2 subluxation secondary to rheumatoid arthritis. (B) Intraoperative lateral X-ray image shows the implantation of screws at C1-C2 through the retractor. (C) Intraoperative lateral X-ray image of the final C1-C2 construct.





**Figure 5.** (A): Preoperative cervical tomography showing type II dens fracture. (B) Postoperative anteroposterior X-ray view shows C1-C2 construction. (C) Postoperative lateral X-ray view of the construction. (D, E). Postoperative coronal and sagittal CT scan showing adequate trajectory and placement of screws. (F) Scar at the surgical incision site at 24 months of follow-up. CT: computed tomography.

**Table 2.** Clinical characteristics

Variables	Value median (IQR)
Blood loss (mL)	300 (250)
Surgery time (min)	130 (50)
Hospital stay (hr)	34 (14)
Level of pain 30 minutes before surgery according to VAS (median, IQR)	8 (1)
Level of pain 3 months after surgery according to VAS (median, IQR)	4(1)

IQR: interquartile range, VAS: visual analog scale.

DISCUSSION

Craniocervical diseases leading to atlantoaxial instability pose a surgical challenge. The initial surgical management of atlantoaxial instability was reported by Mixter and Osgood,

who utilized a braided silk suture encircling the posterior arch of C1 beneath the spinous process of C2 [3]. Since then, various posterior fixation surgical procedures have been described to address this issue [1,2,4-6].

Dorsal wiring has demonstrated fusion rates of 89% to 93%, with complications being infrequently reported. Nonunion is a well-known complication of these techniques [3]. In 1987, Magerl and Seemann [6] first described transarticular atlantoaxial arthrodesis, which requires a midline dorsal incision to expose the posterior elements of C1-C3, with particular attention paid to the atlantoaxial facet joint [3]. Fusion rates in this technique range from 96% to 99% [3].

In 2001, Harms described a dorsal approach involving subperiosteal dissection from the occiput to C3 [3,5]. C1 lateral mass screws are inserted from an entry point located at the

middle junction of the C1 posterior arch and the midpoint of the inferior aspect of the lateral mass [5]. Preoperative imaging determines the entry point for inserting pedicle screws in a convergent and cephalad orientation from 20° to 30° on the medial and cranial quadrant of the isthmus surface of C2 [3,5]. The reported osseous fusion rates range from 94% to 100%. Our study demonstrated osseous fusion of the atlantoaxial joint in 99% of the patients.

Vertebral artery injury is a major concern with C1 transarticular screw fixation, although its incidence has been reported to be less than 3% [12]. With the use of Harms' method in our minimally invasive approach, all inserted screws were 3.5 to 4.0 mm in diameter, and no vascular injuries occurred. The natural anatomical corridor formed by the posterior major capitis and the obliquus capitis inferior muscles allows for adequate screw insertion angulation at a safe distance from the vertebral artery. Accurate preoperative planning is crucial and should involve important aspects of the patient's vascular and osseous anatomy, such as V3 (third segment of vertebral artery) and C1 posterior arch relation, ponticulus posticus, spina bifida, among others. We also consider it important to insert the C1-C2 screws under direct vision and confirm the final position with x-rays.

The incidence of surgical site infection in posterior cervical surgery has been reported to be between 3% to 10% [11-14]. Diabetes has been identified as an independent factor increasing postoperative complications in cervical spine surgery [15]. We found a 2.1% incidence of surgical site infection with our approach. Only one postoperative complication occurred in a diabetic patient as a superficial wound infection 13 days after surgery. No surgical revision was necessary, and it was accurately controlled with antibiotics.

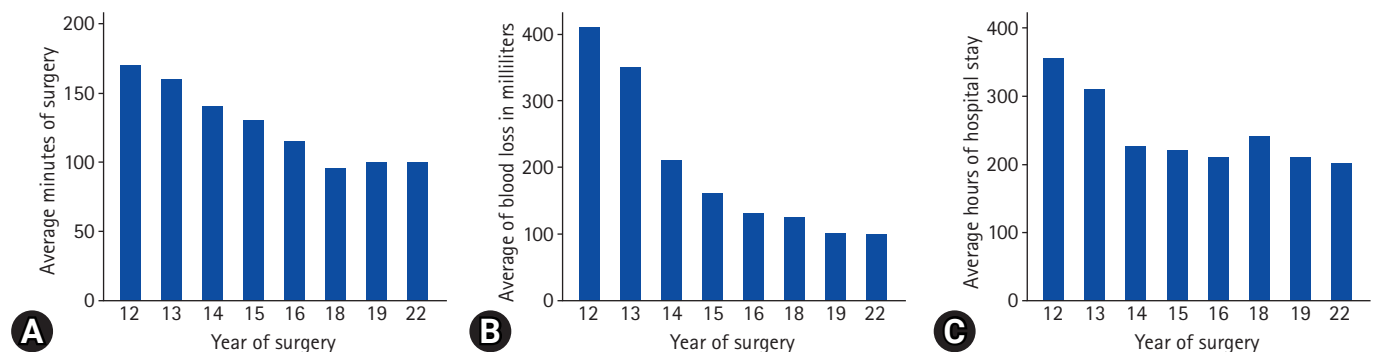
We observed an improvement in the perception of pain

according to VAS at 3 months postoperative. However, due to the different pathologies and clinical presentations of patients before surgery, further studies are necessary to determine the statistical significance of these findings. During the postoperative follow-up, no progression of preexisting weakness was reported. Paresthesia was the symptom that persisted the most after surgery.

Minimally invasive techniques have reduced muscle atrophy, intraoperative blood loss, and improved postoperative pain control [16,17]. Our approach uses two small paramedian incisions (less than 3 cm) following a natural anatomical corridor that preserves the medial cervical tension band. This approach provides more biomechanical stability to the construct, reduces postoperative pain, and shortens the inpatient stay with an average hospitalization time of 34 hours since hospital arrival.

Raut et al. [18] reported their 5-year experience with C1-C2 minimally invasive transarticular fixation, which showed a progressive reduction in operative time and blood loss over the evaluated period by exposing perioperative parameters in quartiles. The learning curve of our surgical technique has also demonstrated a tendency to reduce operative time, blood loss, and hospitalization over the last decade (Figure 6).

The limitations of this study should be highlighted, mainly because it is a retrospective study. It does not have a control cohort to compare the results, which limits the interpretation of the findings. However, during the period evaluated, a trend was observed in the improvement of clinical results with a good fusion rate. Further prospective studies comparing open C1-C2 stabilization with our minimally invasive technique could confirm the benefits of preserving the occipital-cervical tension band.



**Figure 6.** (A) Average time of surgery (min) between 2012 and 2022. (B) Average blood loss in surgery between 2012 and 2022. (C) Average length of hospital stay (hr) between 2012 and 2022.

## CONCLUSION

Our minimally invasive approach, which utilizes a natural anatomical corridor to fuse the atlantoaxial joint with C1 lateral masses and C2 pedicle screws bilaterally, has demonstrated safety and efficacy. We preserve the occipital-cervical tension band to avoid affecting the biomechanical stability of the construct. Based on our results and observed trends, surgical outcomes improve as the surgeon becomes more proficient in the surgical technique. Further prospective studies comparing open C1-C2 stabilization with our minimally invasive technique could confirm the benefits of preserving the occipital-cervical tension band.

## NOTES

### Ethical statements

The ethical implications of this study center on the well-being and autonomy of the patients who underwent the minimally invasive surgical technique for C1-C2 fixation. It is important to note that the study received approval from the appropriate ethical review board before being conducted, which ensures that the research adhered to ethical standards and regulations. Additionally, the study obtained informed consent from all patients, which indicates that they were fully aware of the risks and benefits of the procedure and willingly agreed to participate.

### Conflict of interest

No potential conflict of interest relevant to this article.

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# Minimally Invasive Approach to Decompression for Chiari Malformation Type 1

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**Objective:** Chiari malformation type 1 (CM1) is a congenital hindbrain abnormality characterized by downward displacement of the cerebellar tonsils through the foramen magnum. The widespread accessibility of advanced technologies and imaging modalities has led to an increase in the popularity of minimally invasive (MIS) techniques in cranial and spinal pathologies.

**Methods:** The study was conducted at a university hospital in Bogotá, Colombia. All data were obtained from the database of the hospital's Neurosurgery Department. After institutional review board approval, the medical records of patients who underwent MIS posterior fossa decompression for CM1 were retrospectively reviewed.

**Results:** Thirty-six patients underwent posterior fossa decompression through a minimally invasive approach during the study period. Nineteen patients met the inclusion criteria and were included in the data analysis. The patients' chief complaints were headache (78.9%) and neck pain (57.9%). The average surgical time was  $158.2 \pm 50.5$  minutes, with no significant difference in timing among different specialists. The most common postoperative complications were associated with dura closure, including 6 patients with pseudomeningocele and one patient with cerebrospinal fluid leak.

**Conclusion:** Different surgical techniques have been proposed for posterior fossa decompression of CM1. In the present study, we favor a minimally invasive approach to the craniocervical junction to preserve as much of the normal anatomy as possible and avoid alterations in spinal biomechanics.

**Key Words:** Arnold-Chiari Malformation, type 1, Minimally invasive surgical procedures, Cervical vertebrae

## INTRODUCTION

Chiari malformation type 1 (CM1) is a congenital hindbrain abnormality characterized by downward displacement of the cerebellar tonsils through the foramen magnum [1]. It is defined as herniation of the cerebellar tonsil below the foramen

magnum of >3 mm in children and 5 mm in adults [2]. The most common symptom in both pediatric and adult population is pain or headache within the occipital and cervical regions [2].

These abnormalities have been associated with alterations of normal cerebrospinal fluid dynamics, which result in cerebellar and bulbar dysfunction symptoms [1]. Other related conditions



include syringomyelia and hydrocephalus [2]. Syringomyelia is defined at magnetic resonance imaging (MRI) as the presence of single or multiple fluid-filled cavities within the parenchyma of the spinal cord [3]. After the advent of MRI, estimated prevalence of syringomyelia ranged from 1.9 to 8.4/100,000 [3-5]. About 50% of these patients have severe neurological damage and chronic progressive disability with complete loss of independence [3]. Prognostically speaking, even more unfavorable is the presence of syringobulbia in which swallowing and breathing bulbar centers are involved [3]. Surgery is advised for the patients' symptomatic control or in cases when the latter conditions are clinically evident [1].

The craniocervical junction represents a complex transitional zone between the cranium and the spine [6]. It is a biomechanical and functional unit comprising bone, ligament, and soft tissue housing the spinal cord, and critical neurovascular structures [6,7]. Proper knowledge and study of these anatomical structures allows the implementation of new techniques and approaches [7].

The widespread accessibility of technological and imaging advancements has led to an increase in popularity of minimally invasive (MIS) techniques in cranial and spinal pathologies. Compared to other open techniques, the possible benefits include smaller incisions and less tissue trauma with preservation of muscles and ligaments which are fundamental for spinal biomechanics and stability of the craniocervical junction. In the postoperative phase, MIS to the posterior cranial fossa is frequently associated with reduced bleeding, fewer infection rates, better pain management, and quicker recovery periods [1,8]. The safety and efficacy of the procedure could be jeopardized by the significantly smaller surgical corridors and limited operative field exposure. In the present study, we describe our technique, and report our 10-year experience of MIS posterior fossa decompression for CM1.

## MATERIALS AND METHODS

### 1. Study Population

The study was conducted at a single center in Bogotá, Colombia. All data were obtained from databases of the Neurosurgery Department of the hospital. After institutional review board approval, medical records of patients who underwent a MIS posterior fossa decompression for CM1 over a 10-year period (January 2012 to December 2022) were reviewed retrospectively. CM1 was defined as a downward displacement of tonsils 5 mm or more below the lower limit of the posterior

cranial fossa. All MIS treatments were performed by two spine surgeons, who are experienced in performing a variety of MIS spinal procedures. Patients with other Chiari malformations, previous decompressive surgery, unstable craniovertebral junction requiring fusion, and cerebrospinal fluid (CSF) abnormalities requiring diversion procedures were excluded from this study.

### 2. Data Collection

Baseline patient information such as age, sex, and past medical history were collected. Relevant symptoms and symptom duration were recorded. Operative information regarding type of surgery, duration of surgery, and intraoperative bleeding were obtained from operative notes. Post-operative data such as length of stay, recurrence or onset of symptoms, clinical and radiological changes were obtained. Patients were stratified by Chicago Chiari Outcome Scale (CCOS) for assessing the surgical benefits ranging from 4 (severely incapacitated) to 16 (excellent outcome) [8].

All patients underwent a postoperative computed tomography (CT) scan the day after surgery. MRI was ordered for all patients at three months. Outcomes were evaluated at the last follow-up visit using the CCOS. Finally, the esthetic component of the incision was independently evaluated by 4 examiners using the Vancouver Scar Scale (VSS) ranging from 0 (barely notable scar) to 13 (Severely pathologic scarring) [9]. All significant complications were recorded and treated accordingly.

### 3. Statistical Analysis

Statistical analyses were performed using RStudio Desktop Software 2022 Version (Posit). Descriptive statistics were performed to determine means and standard deviations for the different variables.

### 4. Indication

Indications for surgery in patients with CM1 have been a motive of controversy, especially considering diagnosis depends on radiographic findings that may be incidental. In the setting of tonsillar herniation some clear indications for surgery include the presence of associated syrinx, spinal malformation, or development of neurological deficit secondary to brainstem compression [10]. A survey for the American Society of Pediatric Neurosurgeons demonstrated surgery is reserved for symptomatic patients while asymptomatic subjects are followed

clinically and radiologically [11]. Patients with CM1 may display a variable constellation of symptoms including nausea, vertigo, and neck pain. Nonetheless, intractable occipital headache exacerbated by Valsalva maneuvers is the most common one [11]. The subjective nature of headaches and their multiple etiologies create considerable debate on operating patients with this sole condition. The impact on quality of life is crucial when deciding to operate on patients who only present with associated headache.

Minimally invasive surgery (MIS) is a surgical approach that utilizes small incisions, specialized instruments, and advanced imaging technology to access and treat the affected area. All patients treated in our study were symptomatic and had failed conservative treatment with medication and physical therapy. Patient selection is crucial for obtaining positive outcomes with minimally invasive approaches. The indications we use for deciding on a minimally invasive approach for CM1 include [1,8]:

1. Syringomyelia: CM1 is often associated with the development of fluid-filled cavities within the spinal cord called syrinxes. MIS approaches can be an effective treatment for syringomyelia, particularly in cases where the syrinx is small and located in the cervical or upper thoracic spine [3].
2. Younger patients: Minimally invasive surgery may be preferred in younger patients, as minimal bone removal and soft tissue trauma can help preserve the integrity of the skull and spine, which is important for long-term spinal stability [12].
3. Tonsillar herniation <20 mm: Patients with tonsillar herniation smaller than 2 cm may be good candidates for a minimally invasive approach, as the procedure is less invasive and can still provide significant symptom relief [12,13]. Patients which may require intervention of C2 or lower cervical levels are not candidates for minimally invasive approach.
4. Experienced surgeon: MIS for CM1 requires specialized training and expertise. Patients who are considering MIS should seek out a surgeon who has experience with this technique and a proven track record of success [12].

It is important to note that the suitability of MIS for CM1 is determined on a case-by-case basis, and each patient's individual needs and circumstances must be considered when deciding on the most appropriate treatment approach. Patients with other Chiari malformations, previous decompressive surgery, unstable craniovertebral junction requiring fusion, and cerebrospinal fluid (CSF) abnormalities requiring diversion proce-

dures were excluded from this study.

## 5. Surgical Procedure

### 1) Pre-operative Planning

A thorough history and physical examination, regular preoperative blood work, and pre-anesthetic risk profile are required prior to surgery. It's critical that patients and their families comprehend the aims of surgical therapy. The aim is to avoid future neurologic deficit and reduce syrinx growth in the syringomyelia patient. The objective in patients who also experience other symptoms, like headaches, is to lessen the frequency and severity of those that are caused by CM1.

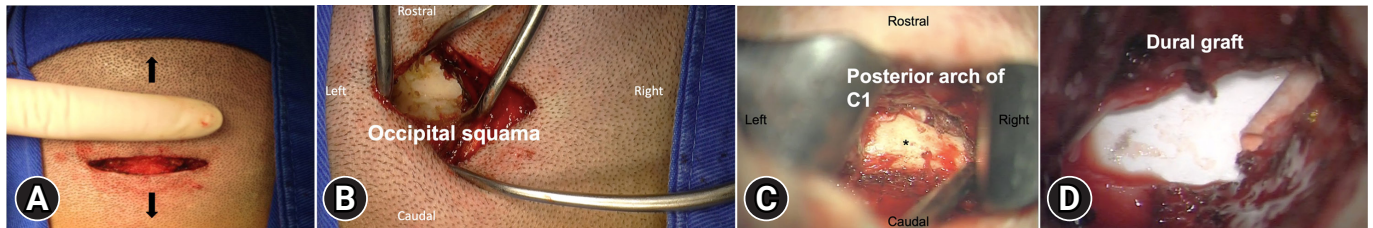
### 2) Patient Positioning and Skin Marking

After induction of general anesthesia, the patient was placed in prone position on a standard operating table, the head was secured in the Mayfield clamp (Integra, Life Sciences, Cincinnati, Ohio, United States). Appropriate padding is used to support the chest and hips, leaving the abdomen free. The neck was placed in flexion and the shoulders were retracted caudally and fixed to the operating table using adhesive tape. The posterior occipital area was prepared and shaved for surgery. A 4 cm horizontal incision was marked immediately under theinion.

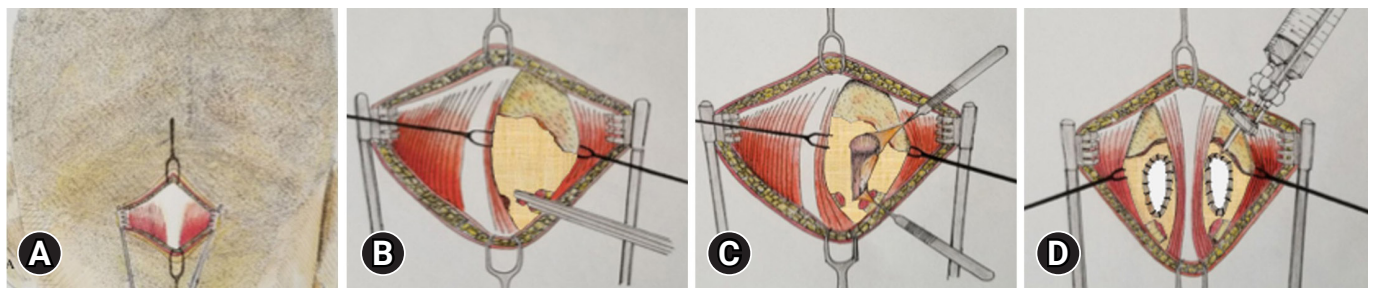
### 3) Skin Incision and Surgical Procedure

Scalp and minimal electrocautery were used on skin and subcutaneous tissue to expose the posterior neck muscles. Bilateral paramedian trans muscular dissections were then performed through the trapezius and the semispinalis capitis to reach the posterior arch of C1 and the occipital squama. Following the orientation of the muscle fibers, the dissection was extended caudally in a sagittal plane to expose the posterior border of the foramen magnum, the posterior atlantooccipital membrane and the posterior arch of C1 (Figure 1). Self-retaining retractors were then placed to laterally displace the rectus capitis major. Once the posterior arch of C1 is identified, a subperiosteal dissection of the vertebral artery canal is performed. A delicate elevation and lateral displacement of the artery is performed to achieve a complete resection of the posterior arch up to the lateral mass.

The suboccipital venous plexus, if encountered, was coagulated with bipolar forceps. Soft tissue dissection was followed by a suboccipital craniectomy 3 cm wide accomplished with a high-speed drill and extending all the way down to the foramen magnum to visualize the dura. After osseous decompression, the epidural adhesion band was coagulated and carefully re-



**Figure 1.** Minimally invasive CM1 posterior fossa decompression. (A) 4 cm horizontal skin incision under theinion. (B, C) Bilateral muscular dissection is performed through the trapezius and semispinalis capitis. We continue the dissection caudally after reaching the occipital squama to reveal the foramen magnum's border, the atlantooccipital membrane, and the posterior arch of C1 (asterisk). (D) Dural graft covering the dural incision. (E) Muscle closure with absorbable suture. Black arrows indicate the position of the head in each image.



**Figure 2.** Surgical technique for CM1 MIS PFD. (A) Skin incision. (B) Muscular dissection is performed bilaterally, here we see the right paramedian trans muscular dissection, through the trapezius and the semispinalis capitis, exposing the occipital squama. Upon reaching the occipital squama we continue the dissection caudally to expose the edge of the foramen magnum, the atlanto occipital membrane and the posterior arch of C1. (C, D) Posterior fossa decompression (craniectomy 3 cm in diameter and resection of posterior arch of C1) with a high-speed drill. After bone resection the epidural adhesion band is coagulated and removed. Bilateral 3 cm durotomies are performed, closure with dural patch and reinforcement with fibrin sealant or nylon suture is done.

moved (Figure 2).

Opening the dura was performed under the microscope using bilateral vertical durotomies of approximately 3 cm, it was typically performed in a caudal to rostral fashion (Figure 2). We then proceeded to close the dural defect by using one of three techniques of duraplasty; a synthetic duramater substitute (non-autologous graft) sutured with a No 5-0 nylon suture, non-autologous graft with underlay technique and fibrin sealant (Tisseel, Baxter) or autologous cervical fascia graft sutured with No 5-0 nylon suture (Figure 1, 2). Finally, a standard layered closure was done; muscle and subcutaneous tissue with absorbable sutures and the skin with nylon thread.

## RESULTS

Thirty-six subjects underwent posterior fossa decompression through a minimal invasive approach during the study period. Nineteen patients met inclusion criteria and were used for data analysis. Patients had an average age of 34.6 years, and five pediatric patients (26.3%) were included (Table 1).

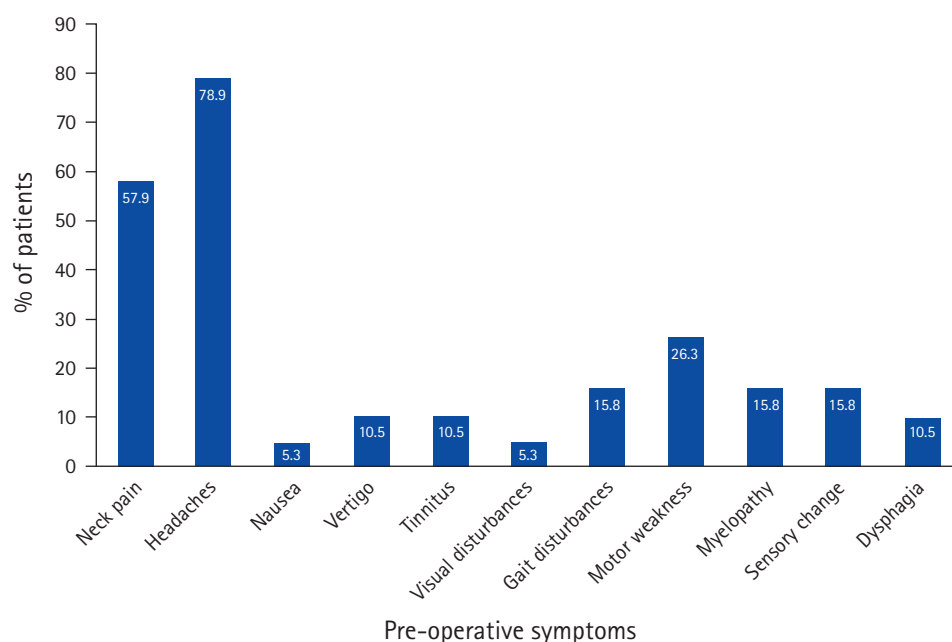
**Table 1.** Patient characteristics

Demographics	
Women (%)	89.5
Average age (year)	34.6 ± 17.5
Pediatric patients (%)	26.3
Average follow-up (month)	29 ± 22

## 1. Patient Characteristics and Re-operative Symptoms

All nineteen patients were treated with posterior fossa decompression with a MIS approach for CM1 related symptoms as the main indication for surgery. The average age at surgery was 34.6±17.5 years and we had patients from 5 to 61 years. 89.5% of the patients were women (Table 1).

The chief complaint of the patients was headache (78.9%) and neck pain (57.9%). Tinnitus, vertigo, and dysphagia had a prevalence of 10.5% each (Figure 3). One patient reported nausea and another subject referred visual alterations. Motor weakness was the most common alteration on neurologic examination present in 5 patients. Myelopathy, gait disturbances and sensory changes had a prevalence of 15.8%.



**Figure 3.** Pre-operative symptoms.

## 2. Pre-operative Imaging

Every patient taken into surgery was initially studied with brain and cervical MRI and CT scan. MRI was used to confirm diagnosis of CM1 and rule out additional causes of tonsillar displacement. Cervical CT scan was mandatory in preoperative studies to characterize any vascular or osseous anomaly in the craniocervical junction. Tonsillar herniation ranged from 5 to 17 mm, with an average  $8.6 \pm 2.9$  mm. Syrinx was present in 68.4% of patients, in which a complete neuroaxis MRI was done to determine the size of the syringomyelia and the presence of associated scoliosis (Figure 4). Four of the patients (21.1%) had scoliosis and were studied with a panoramic x-ray, thoracic and lumbar MRI in search of secondary causes of scoliosis.

## 3. Surgery

Operative procedures were done in one hospital by two different neurosurgeons using the technique illustrated previously. The average surgical time was  $158.2 \pm 50.5$  minutes, with no significant difference in timing between different specialists (Table 2). Depending on the neurosurgeon in charge of the surgery different duraplasty methods were used. In four patients an autologous graft of cervical fascia was used to close the dura defect, while in the other 15 subjects a non-autologous graft was preferred. In 47.4% of the patients the graft was sutured to the dura with a nylon suture. For the duraplasty of the other

52.6% of patients an underlay technique and fibrin sealant were used. We had no reports of intraoperative complications. The average hospital stay was 3.7 days, with hospitalization ranging from 2 to 13 days (Table 3).

## 4. Follow-up

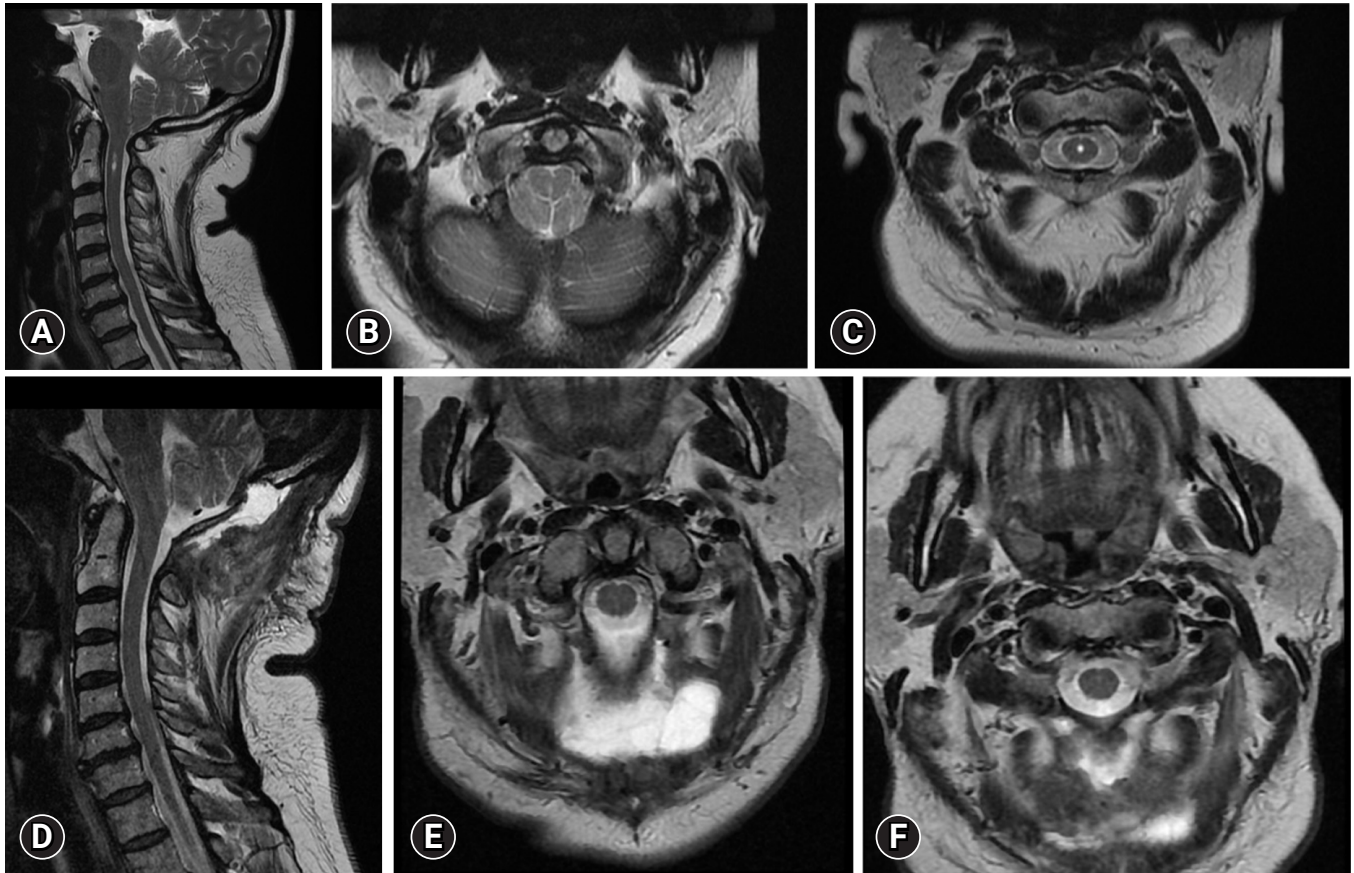
All patients underwent a postoperative CT scan the day after surgery. The first follow-up visit was scheduled 15 days after the procedure and thereafter patients were evaluated from 1 up to 74 months. MRI was ordered for all patients at three months (Figure 4); However, for 26.3% the postoperative MRI could not be retrieved and assessed.

## 5. Post-operative Symptoms and Complications

The most common post-operative complications were associated with dura closure, including 6 patients with pseudomeningocele and one patient with CSF leak (Table 3). The patient with CSF leak developed bacterial meningitis which was treated with antibiotics and had a favorable outcome. Half of the patients with pseudomeningocele had associated chemical meningitis.

We segregated our data to determine the duraplasty method used and compare complications (Table 4). In ten patients non-autologous graft was used and closed with an underlay technique with fibrin sealant. In this group we had our only





**Figure 4.** Comparison of pre-operative (A–C) and post-operative (D–F) images (cervical MRI T2-sequence) of a 48-year-old patient who presented with a history of occipital headache and upper limb weakness that exacerbated with Valsalva maneuvers. The patient underwent minimally invasive posterior fossa decompression without any complications. Pre-operative images: (A) Sagittal section, showing syrinx extending to the level of the vertebral body of C2. There is evidence of descent of cerebellar tonsils 7 mm below the foramen magnum. (B) Axial section at the level of the middle third of the odontoid, showing tonsillar descent. (C) Axial section at the level of the C3 vertebra showing syrinx. Post-operative images: (D) Sagittal section showing resolution of syrinx, C1 posterior arch laminectomy and adequate decompression of the posterior fossa. (E) Axial section, showing laminectomy of the posterior arch of C1. (F) Axial section at the level of the C3 vertebra showing resolution of the syrinx.

**Table 2.** Surgical variables in minimally invasive posterior fossa decompression for Chiari malformation type 1

Surgical variables	
Time of surgery (min)	158.2 ± 50.5
Blood loss (mL)	154.7 ± 84.9
Autograft (no. of patients)	4
Non-autologous graft (no. of patients)	15
Nylon suture (no. of patients)	9
Fibrin sealant (no. of patients)	10
Intraoperative complications	0
Average hospital stays (d)	3.7

CSF leak who developed bacterial meningitis, and two pseudomeningocele, one who had associated chemical meningitis. Five subjects had duraplasty with non-autologous graft and nylon suture, three of them developed pseudomeningocele and two had chemical meningitis. Only four patients had autograft

**Table 3.** Postoperative complications

Complications	No. patients (%)
CSF leak	1 (5.3)
Pseudomeningocele	6 (31.6)
Hematomas	0
Chemical meningitis	3 (15.8)
Bacterial meningitis	1 (5.3)
Re-operation	1 (5.3)

CSF, cerebrospinal fluid.

for the duraplasty, one of them developed a pseudomeningocele and none had meningitis. We had no hematomas and no mortality associated with this procedure.

Both clinical and radiographic changes were evaluated after surgery. The CCOS was used to evaluate patients. The average CCOS was 14.3±1.8, with 89.5% of patients having a score

**Table 4.** Comparison of duraplasty methods

	No. patients	Pseudomeningocele	CSF leak	Chemical meningitis	Bacterial meningitis
Non-autologous graft+fibrin sealant	10	2	1	1	1
Non-autologous graft+nylon suture	5	3	0	2	0
Autograft+nylon suture	4	1	0	0	0

CSF, cerebrospinal fluid.

between 13–16, showing improvement and good outcome. One patient had a score of 8 and was taken for a reintervention which involved a C2–C3 laminectomy and resection of a cervical arachnoidocele. This was performed to widen the posterior fossa decompression. Patients had a post-operative MRI to evaluate complications and changes, unfortunately 5 of these could not be assessed. An improvement in the posterior fossa was evident in 68.4% of patients. The subject who had the CCOS score of 8 had no change in his posterior fossa image and was taken to a second surgery. Of the patients with a pre-operative syrinx, 46.2% had an improvement in the size of the syrinx and 23.1% were unchanged. There was no increase in syrinx in postoperative images. The VSS was used to assess the esthetic component of the incision, with 87% of the patients with barely notable scars.

## DISCUSSION

Chiari malformation type 1 was originally described by Hans Chiari in 1896 as an “elongation of the tonsils and the medial parts of the inferior lobes of the cerebellum into con-shaped projections which accompany the medulla oblongata into the spinal canal” [14]. A common treatment for symptomatic CM1 is posterior fossa decompression; there is debate around the technical aspects of surgery, however, the outcomes and risks of surgery are well documented [14].

The first Chiari decompression procedure was performed by James Gardner in 1950 by a wide craniectomy to open the 4th ventricle and plug the obex with a piece of muscle [14]. Since then, multiple variations have been incorporated into Chiari surgery. Sub-occipital posterior fossa decompression with atlas laminectomy and an augmentative duraplasty are considered the standard surgical approach for most symptomatic patients [15]. Decompression of the posterior fossa often yields favorable results. According to published studies, symptoms improve in 60% to 100% of patients, and the success rate for resolving syringomyelia is similar [16].

Different minimally invasive surgical techniques have been proposed for posterior fossa decompression of CM1. Caffo et al. [13], reported twenty-six patients with CM1 with and without

syringomyelia who underwent a MIS PFD through a 3×3 cm craniectomy with the removal of the most median third of the posterior arch of C1 and duraplasty [17]. A midline skin incision was performed starting 1 cm above theinion to the spinous process of C2; the fascia and muscles were incised and dissected in a subperiosteal fashion until the occipital bone and the posterior arch of C1 were exposed [13]. Signs and symptoms improved in 76.9% of cases [13]. In their experience the rate of complications was 23% including fistula, worsening symptoms, and respiratory impairment [13].

Quillo-Olvera et al. [17], proposed a micro-decompression of the suboccipital bone, posterior arch osteotomy of C1, and duraplasty through a 2 cm midline incision under surgical microscope magnification. When the suboccipital bone was identified, the medial occipital insertion of the semispinalis capitis muscle, rectus capitis posterior minor, and the medial portion of the rectus capitis posterior major muscles were detached on each side [17]. We believe that even though small craniectomies and incisions were used, the need to detach the muscles may have increased postoperative pain and alter spinal biomechanics; variables that were not studied.

Teo et al. [1] reported a MIS technique in which a tube is inserted through the incision under microscopic guidance to expose the foramen magnum and posterior arch of C1. Five patients underwent this technique, and 9 patients underwent open posterior fossa decompression. One MIS patient and 2 patients from open posterior decompression developed CSF leak post-operatively and required repeat surgery for repair [1]. MIS posterior fossa decompression conferred higher rates of post-operative improvement in quality-of-life measures, and lower rates of post-operative complications [1].

We propose a minimally invasive technique using naturally occurring trajectories to complete the standard surgical objectives. Taking advantage of spaces between muscles obviates the need for muscle lesioning and helps improve post-operative pain, without impairing proper visualization and size of decompression. As documented, a smaller than average incision is enough to create an anatomical corridor wide enough to expose all the surgically relevant structures (occipital squama, posterior arch of C1 and the duramater extending from the pos-

terior fossa all the way down to the cervicomedullary junction). Furthermore, conservation of the nuchal ligament attachment plays an important role in avoiding cervical mechanical and radiologic instability [18].

Due to the extensive exposure obtained, our approach creates a dynamic corridor that allows for more invasive modifications to suit each surgeon's preferences. Without further exposure or dissection, the posterior arch of C1 can be removed, adequate durotomies with duraplasty, arachnoid dissections, and even tonsillectomies can be carried out if necessary. Although the best procedure is still unknown, there is a decent amount of agreement on the size of the occipital bony resection, and it is typically advised to perform a craniectomy that is between 3–4 cm in diameter extending all the way to the foramen magnum [14]. With the use of our MIS strategy, we were able to remove the complete posterior arch of C1 and perform appropriate decompressive craniectomies that extended all the way to the craniocervical junction. Also, to broaden the decompression, we execute bilateral 3 cm long dural apertures with duraplasty and resect the epidural adhesion band at the cervicomedullary junction.

According to the degree of decompression obtained with the durotomy and the direct visualization of the cisterns, we think the decision to coagulate the cerebellar tonsils should be taken intraoperatively. In none of our cases was a tonsillectomy necessary. However, they were visualized with the MIS approach and if necessary, the tip of the tonsils could be coagulated through this surgical corridor, a practice that is common in some institutions [14,19].

Length of stay (LOS) was compared to a meta-analysis reported by Lu et al. [20]. LOS and blood loss ranged from 3.3 to 6.4 days and 47 to 80 mL, respectively. When compared to our study population, our overall LOS was slightly lower with a mean of  $3.7 \pm 2.42$  days. The estimated blood loss in our study was 154 mL, significantly higher than that reported in literature [20]. We acknowledge that there is a discrepancy between our findings and previous research, and we believe this may be related to an overestimation of blood loss due to human error. As we noted, extreme values can have a significant impact on the mean value, especially in small sample sizes. Nonetheless, during the MIS procedure we observed that smaller muscular dissection helped keep the subarachnoid space clear from blood contamination which might diminish the risk of postoperative arachnoid adhesions and aseptic meningitis.

Clinical improvement has been reported to range from 50% to 86% in recent research, but the parameters used to quantify this vary between authors [21,22]. Our outcome measurements

were based around three distinct factors: scar development, objective clinical indicators, and pain and associated symptoms. We observed no symptom recurrence after the follow-up. We used the Chicago Chiari Outcome Scale to determine if there was an objective improvement after surgery, evidencing that 89.5% of patients had scores between 13–16, showing a good outcome. Only one of our patients had a low CCOS score and was taken to a reintervention.

We decided to implement the Vancouver Scar Scale to assess the esthetic outcome of the intervention. As far as we are aware, scarring and neck muscle atrophy in individuals receiving posterior fossa decompression for the treatment of CM1 have not been investigated. We believe that a smaller horizontal incision that remains hidden below theinion and less muscle dissection with preservation of muscles and ligaments which are fundamental for spinal biomechanics and stability of the craniocervical junction causing a lower incidence of muscle atrophy and a better esthetic result.

Post-operative MRI demonstrated a reduction in syrinx size in 46.2% of patients. Unfortunately, we had no image control in 30.8% of subjects, which limits our analysis. Literature reports syrinx improvement in around 60% of patients, but this change may take up to 30 months, and may be missed in initial follow up [10]. Though radiological findings are important for outcome analysis, clinical improvement may appear first, and our results are congruent with those described in other studies, demonstrating an appropriate decompression through our minimally invasive technique.

Overall complications associated with posterior fossa decompression for CM1 vary widely through literature and depend on the type of surgery performed and the surgeon's experience [23]. CSF leak, aseptic meningitis, and pseudomeningocele are the most common complications [6]. Graft complication rates reported in studies range between 18 and 40% [24]. In our population pseudomeningocele was the most frequent complication, occurring in 31.6% of our patients, and disappearing during follow up. 15.8% of the patients had chemical meningitis. Both complications were associated with non-autologous grafts, as reported in the Park-Reeves Syringomyelia Research Consortium study [24]. It is worth mentioning that in the three patients in our cohort that developed chemical meningitis a bovine graft was used. There was no significant difference between complications using nylon suture vs. underlay technique with fibrin sealant.

The limitations of this involve a small sample size, with no follow up MRI in every patient. This is a retrospective study without a control group, limiting the interpretation of the

findings. However, during the period evaluated, a trend was observed in the improvement of clinical results. Further prospective studies comparing out technique with other common techniques could confirm the benefits of performing this minimally invasive approach.

## CONCLUSION

Different surgical techniques have been proposed for posterior fossa decompression of CM1. In the present study, we favor a minimally invasive approach to the craniocervical junction to preserve as much as normal anatomy as possible and avoid alterations in spinal biomechanics. The surgical technique that we have described takes advantage of a minimally invasive corridor to decompress the posterior fossa while preserving the posterior tension band with minimal muscle disruption. We believe this approach presents several advantages over traditional midline procedures. However, further investigation of this technique, with a prospective larger sample size and long-term clinical and radiologic follow-up, is necessary.

## NOTES

### Ethical statements

The study received approval from the appropriate ethical review board before being conducted, which ensures that the research adhered to ethical standards and regulations. In addition, the study obtained informed consent from all patients, which indicates that they were fully aware of the risks and benefits of the procedure and willingly agreed to participate.

### Conflict of interest

No potential conflict of interest relevant to this article.

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# Clinical Results and Review of Techniques of Thoracic Endoscopic Unilateral Laminotomy with Bilateral Decompression (TE-ULBD) Using the Outside-In Technique for Thoracic Ossified Ligamentum Flavum

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**Objective:** Uniportal full endoscopic thoracic endoscopic surgery can be performed through transforaminal and interlaminar approaches. The interlaminar approach is commonly described as thoracic endoscopic unilateral laminotomy for bilateral decompression (TE-ULBD), which is typically indicated for pathologies such as ossified ligamentum flavum and other posteriorly based compressive pathologies. TE-ULBD decompresses the central and lateral recesses of the thoracic spinal canal. Both the outside-in (over the top of ligamentum flavum) and inside-out (under the ligamentum flavum) approaches can decompress the thoracic spinal canal through the uniportal interlaminar endoscopic route.

**Methods:** A retrospective clinical cohort evaluation of patients who underwent TE-ULBD was performed from January 2018 to December 2021

**Results:** A cohort of 50 cases of TE-ULBD with a mean age of 65 years old were evaluated. The complication rate was 5.4% and the reoperation rate was 2%. Statistically significant mean VAS improvements were found at 1 week, 6 months, and the final follow-up, with changes of  $3.95 \pm 1.49$ ,  $4.95 \pm 1.7$ , and  $5.2 \pm 1.8$  points, respectively. Likewise, the mean Oswestry Disability Index improvements at 1 week, 3 months, and the final follow-up were  $33.8 \pm 9.05$ ,  $40.12 \pm 10.38$ , and  $41.92 \pm 11.26$ , respectively ( $p < 0.001$ ). Significant improvements were found in the cross-sectional area of the spinal canal in the upper endplate, mid-disc, and lower endplate ( $57.62 \pm 50.6$ ,  $89.86 \pm 55.93$ , and  $64.93 \pm 60.91$  mm<sup>2</sup>, respectively;  $p < 0.001$ ).

**Conclusion:** TE-ULBD using the outside-in technique could achieve good clinical outcomes and a low rate of complications in our cohort of patients.

**Key Words:** Spinal stenosis, Endoscopic spine surgery, Minimally Invasive Spine Surgery, thoracic spine, Ligamentum flavum, Omit foraminal ligament

## INTRODUCTION

Thoracic myelopathy is an insidious and debilitating spinal condition leading to gait instability, thoracic back and radicu-

lar pain and lower limb weakness and numbness. One of the common causes of thoracic myelopathy is thoracic ossified ligamentum flavum (OLF). The incidence of thoracic OLF is low [1]. Open posterior thoracic decompression of thoracic OLF is

associated with significant surgical risks and perioperative comorbidities [2,3]. Osman et al. [4] described the rate of complication for open laminectomy of thoracic OLF is approximately 18.4%. One of the common complications of decompressive thoracic OLF surgery is dura tear. Kim et al. [5] and Wu et al. [6] described in separate literature of the use of uniportal Thoracic Endoscopic Unilateral Laminotomy With Bilateral Decompression (TE-ULBD) with good clinical results and lower complication rates. There is an increasing demand for endoscopic spine surgery as a form of minimally invasive surgery with potentially less perioperative morbidities and early mobilization which leads to improved early postoperative surgical outcomes [7,8]. There are limited literature describing the technique of TE-ULBD in the literature [5,6,9]. Most of the literature on thoracic endoscopic decompression focuses on the anterior transthoracic retropleural transforaminal endoscopic thoracic discectomy.

### **Difference between Inside-Out versus Outside-In Thoracic Endoscopic Unilateral Laminotomy with Bilateral Decompression**

In lumbar spinal stenosis with posterior compressive pathologies such as thickened ligamentum flavum and facet cysts, there are several technical approaches described for LE-ULBD to achieve the same target of spinal decompression [10–13]. The main difference focuses on the over the top of ligamentum flavum decompression and under the ligamentum flavum decompression approach of LEULBD, which recently coined as Outside-in by Kim et al. [11] and Inside-out by Lim et al. [14]. In this study, we evaluated the efficacy and outcomes of Outside-in thoracic endoscopic unilateral laminotomy with bilateral decompression.

## **MATERIALS AND METHODS**

This retrospective study was reviewed by institutional review board of Nanoori Hospital, Seoul, Republic of Korea. All patients signed consent to have their data collected for study.

Retrospective clinical evaluation of patients who met indications of Thoracic endoscopic unilateral laminotomy with bilateral decompression (TE-ULBD) were included in the study. These are patients who were included presented with thoracic back pain and/or myelopathy with MRI and CT demonstrated clinically significant thoracic ossified ligamentum flavum. We excluded revision surgery, patients who had concurrent tumor, infection, instability of thoracic spine and fractures. Collection

of pre and postoperative clinical data of Clinical Visual Analog Scale and Oswestry Disability Index, MJOA, Motor Power was done retrospectively in clinical consultation at 1 week post-operative, 6 months post-operative and final follow up. All the included patients underwent Thoracic Endoscopic Unilateral Laminotomy With Bilateral Decompression Using Outside-In Technique.

### **1. Thoracic Endoscopic Unilateral Laminotomy with Bilateral Decompression Using Outside-In Technique**

#### **1) Preparation**

All patients in our cohort underwent general anesthesia and positioned prone on Wilson frame on a radiolucent operating table. The patient's arms were padded and positioned next to the patient.

#### **2) Surgeon Position and Skin Marking**

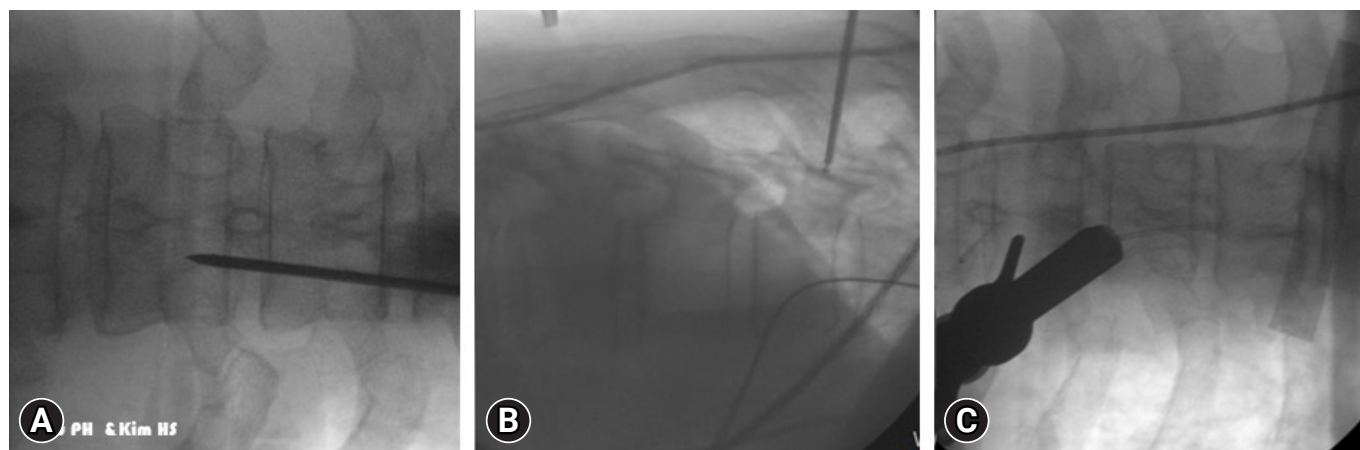
The surgeon stood on the side with the symptoms or the side with more significant stenosis shown on the CT and MRI scan. Careful counting of the correct level of thoracic spine under the fluoroscopic guidance of anteroposterior (AP) and lateral view were performed. The planned skin incision located at the intersection of medial pedicle line and mid disc line on the AP view and on the lateral view of the mid disc of the correct surgical level is described as the “V” point (Figure 1).

#### **3) Serial Dilation and Docking**

Typically, we made a 1 cm skin incision and fascia cut followed by serial dilation and an endoscopic working retractor cannula slide through the dilators to allow smooth insertion of an endoscope (Figure 1). We recommend using a uniportal stenosis scope with approximately 8–10 mm outer diameter endoscope and a 5–6 mm working channel to facilitate the use of endoscopic drill, radiofrequency ablator and Kerison rongeur. The recommended continuous irrigation pressure of normal saline is 25–30 mmHg.

#### **4) Soft Tissue Dissection and Exposure of Bony Anatomy**

Once docking of working cannula on the V point was confirmed on fluoroscopic images, radiofrequency ablation device was used to dissect the muscle and soft tissue to expose the capsule of the facet joint, cephalad and caudal lateral part of the bony lamina surrounding the bony “V” point. Using the endoscope we carefully evaluate the facet joint size so that resection is not taken beyond the midpoint to prevent over resection of the facet joint. We take care not to violate the pars interar-



**Figure 1.** Intraoperative fluoroscopic pictures of right T7/8 thoracic endoscopic unilateral laminotomy with bilateral decompression (TE-ULBD). (A) A skin incision is marked on the medial pedicle of right T8 on anteroposterior view. (B) Corresponding lateral view with a guide wire placed on the medial and mid-pedicle region of right T8. (C) Serial dilation and docking of the retractor tube and endoscope on the right T8 pedicle to prepare for a sublaminar approach in TE-ULBD.

ticularis to maintain segmental stability of the affected level of thoracic spine.

### 5) Outside-In Bony Decompression Endoscopic Drilling

Endoscopic drilling was performed to widen interlaminar space from medial to lateral and cephalad to caudal direction in order to expose the attachment of ossified ligamentum flavum. Care was taken to preserve at least half of the inferior articular facet. The cephalad lamina and the base of spinous process base was drilled in a sublaminar approach to the free edge of ossified ligamentum flavum. Once only paper thin membrane of ligamentum flavum covering the ipsilateral epidural space is seen. We continued to perform endoscopic drilling over the top of ipsilateral and contralateral ossified ligamentum flavum to approach the contralateral cephalad lamina and contralateral ventral portion of inferior articular process and medial half of contralateral superior articular process to the contralateral lateral edge of ligamentum flavum. This is followed by endoscopic drilling on the ipsilateral and contralateral caudal lamina till the contralateral edge of the ligamentum flavum was paper thin. Ossified ligamentum flava of both sides were kept during endoscopic bony drilling to prevent inadvertent dura puncture.

## 2. Gentle Separation of Ligamentum Flavum from Dura and Removal of Ossified Ligamentum Flavum

The exposed thinned-out edges of bilateral OLFs are carefully lifted off from the underlying dura by a blunt endoscopic penfeel. Any underlying adhesion of the OLF is separated by the combination of radiofrequency ablation and penfeel. We

retrieved ligamentum flavum en bloc with forceps or Kerrison rongeurs once the OLF is free of all attachments. If OLF is tightly adhered to the dura, we thin out the OLF by endoscopic drilling and left it as an island of OLF free of attachment to surrounding structures (Figure 2A).

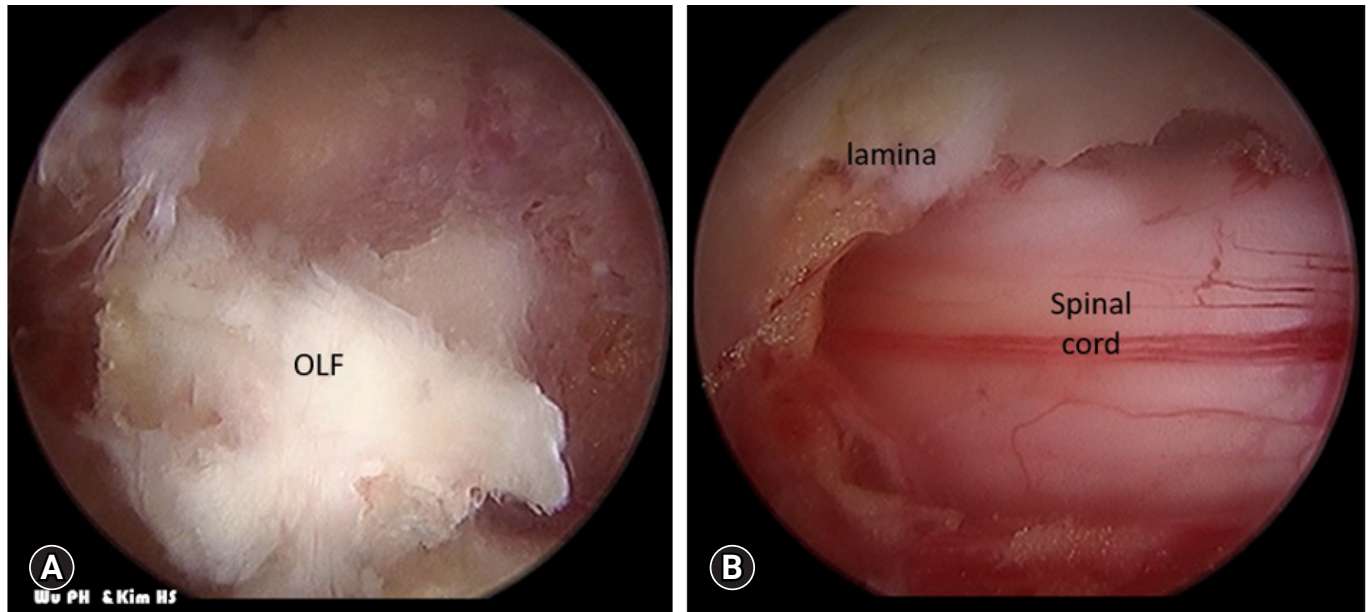
## 3. Final Assessment of Status of Neural Elements and Dura

Neural elements and dura is checked for any dura tear and the thoracic cord pulsation under irrigation fluid. We confirmed under endoscopic vision that bilateral lateral edge of the dura, cephalad and caudal part of dura were decompressed (Figure 2B). Unlike lumbar spine, throughout the entire surgery there should not be any attempt to retract the cord during any step of surgery. A drain was inserted and anchored and skin was closed in layers. We typically removed the drain on postoperative day 1 if drainage is less than 80 mL over 24 hours.

## 4. Statistical Analysis

Clinical data was analyzed with SPSS version 18 statistical analysis software (IBM corporation, New York). The continuous variables were expressed as mean and standard deviation (SD). The paired t-test was used clinical visual analogue scale (VAS), Oswestry Disability Index (ODI), Modified Japanese Orthopaedic Association Score (MJOA) measured at pre-operative, 1 week post-operative, 6 months post-operative and final follow up reported by the patients were analysed. A value of ( $p < 0.05$ ) considered significant within the cohort.





**Figure 2.** (A) Intraoperative picture demonstrates the isolation of thoracic ossified ligamentum flavum (OLF). (B) Complete en bloc removal of OLF with the spinal cord decompressed and pulsating. The authors used a similar approach in thoracic spinal compressive pathologies. A retrospective analysis of clinical outcome of our cohort of TE-ULBD outside in patient cohort was performed.

## RESULTS

After meeting both inclusion and exclusion criteria, 60 levels of TE-ULBD performed in 60 (26 male and 34 female) patients. Forty-seven patients underwent one level, 13 patients underwent 2 levels of TE-ULBD. The patients were recruited from May 2018 to July 2022. The mean follow up was 16.5 (4–47) months. Mean age of the cohort was 65 years old (Table 1).

### 1. Clinical Outcomes

The overall complication rate of TE-ULBD was 5.4%. There was one case of incomplete decompression which was picked up in postoperative MRI, he underwent revision TE-ULBD with successful decompression. There were 2 dural tears were treated with patch blocking repair technique [15]. One of the dura tear patient had paraparesis with partial recovery to power 4 on bilateral lower limbs. The other patient with dura tear had no clinical sequelae. One patient had incomplete decompression and underwent revision TE-ULBD without clinical sequelae and one patient had developed facet cyst after 12 months which was treated conservatively. MacNab score 38% patients with excellent, 55% with good, 3% with fair and 2% with poor results (Table 1).

In TE-ULBD group, there was significant improvement in the mean±standard deviation as compared to preoperative

VAS in postoperative 1 week ( $3.95 \pm 1.49$ ), 6 months ( $4.95 \pm 1.7$ ), and final follow up ( $5.2 \pm 1.8$ ),  $p < 0.001$ . There was significant improvement in the mean±standard deviation as compared to preoperative ODI in postoperative 1 week ( $33.8 \pm 9.1$ ), 6 months ( $40.12 \pm 10.38$ ), and final follow up ( $41.92 \pm 11.26$ ),  $p < 0.001$ . There was significant improvement in the mean±standard deviation as compared to preoperative JOA in postoperative 1 week ( $1.19 \pm 0.92$ ), 6 months ( $1.59 \pm 1.78$ ), and final follow up ( $1.95 \pm 1.4$ ),  $p < 0.001$  (Table 2 and Table 3)

### 2. Radiological Outcomes

In TE-ULBD cohort's radiological outcomes, there was significant statistical increase in decompression cross section spinal canal area (SCA) dimension in postoperative compared to preoperative MRI scan with mean and standard deviation increase of 1) upper disc  $57.62 (\pm 50.6) \text{ mm}^2$ , 2) middle disc  $89.86 (\pm 55.93) \text{ mm}^2$ , 3) lower disc  $64.93 (\pm 60.91) \text{ mm}^2$ ,  $p < 0.001$  (Table 2).

## DISCUSSION

There is an increasing incidence of thoracic OLF being treated surgically [8]. The traditional surgical treatment is posterior laminectomy along with flavectomy to increase spinal canal volume. The laminectomy is performed with open and tubular microscopic approach traditionally [16]. There are limited

**Table 1.** Baseline demographic data and clinical parameters of TE-ULBD

	TE ULBD
Age (mean, range in yr)	65 (31–85)
Duration of symptoms (mean, range in mo)	-
Sex	-
Male	26
Female	34
Levels of operation	-
2 levels of operation	13
1 level of operation	47
Operative time (mean, range in min)	-
Follow-up (mean, range in mo)	16.48(4–47)
Complications (n, %)	4, 5.4%
Preoperative VAS (mean, range)	7.08 (3–10)
Postoperative VAS at 1 wk (mean, range)	3.13 (2–5)
Postoperative VAS at 6 mo (mean, range)	2.13 (1–4)
Postoperative VAS at final follow-up (mean, range)	1.88 (1–4)
Preoperative ODI (mean, range)	66.05 (46–86)
Postoperative ODI at 1 wk (mean, range)	32.25 (22–46)
Postoperative ODI at 6 mo (mean, range)	25.93 (18–42)
Postoperative ODI at final follow-up (mean, range)	24.13 (18–52)
Preoperative JOA (mean, range)	9.37 (6–11)
Postoperative JOA at 1 wk (mean, range)	10.08 (7–11)
Postoperative JOA at 6 mo (mean, range)	10.4 (1–11)
Postoperative JOA at final follow-up (mean, range)	10.63 (7–11)
MacNab's criteria	Excellent: 23 (38%) Good: 33 (55%) Fair: 3 (5%) Poor: 1 (2%)

The final outcome recovery rate was determined using Hirabayashi method: recovery rate (%)=(postoperative JOA–preoperative JOA)/(11 [full score]–preoperative JOA)×100, with the outcomes classified as excellent (75%–100%), good (50%–74%), fair (25%–49%), unchanged (0%–24%), or deteriorated (decrease in score, <0%). The complication rate was calculated as the number of complication/number of cases×100%. TEULBD: uniportal thoracic endoscopic unilateral laminotomy with bilateral decompression using the single block resection technique, TOL: thoracic open laminotomy with bilateral decompression, VAS: visual analog scale, ODI: Oswestry Disability Index, JOA: Japanese Orthopaedic Association myelopathy score, Sato type A: lateral type of ossification of ligamentum flavum with ossification at capsular portion of ligamentum flavum, Sato type B: extended type of ossification of ligamentum flavum with ossification at interlaminar portion of ligamentum flavum, Sato type C: enlarged type of ossification of ligamentum flavum with ossification interlaminar portion with anteromedial thickening, Sato type D: fused type of ossification of ligamentum flavum with ossification at bilateral ligamentum flava fused together at midline, Sato type E: tuberos type of ossification of ligamentum flavum with anterior growth of fused mass of ossification.

literature in thoracic endoscopic decompression. The steep learning curve in orientation of thoracic surgical anatomy and potential implications in incomplete decompression and significant complications are some of the reasons why there are limited publications on this topic [17]. The concept of TE-ULBD is an evolution of development of Lumbar Endoscopic

Unilateral Laminotomy With Bilateral Decompression (LE-ULBD) technique, Lim et al. [14] described inside out (under the ligamentum flavum decompression approach and above the spinal cord) and Kim et al. [11] described outside-in (over the top of ligamentum flavum decompression) approach to decompress the bilateral epidural space lumbar spinal stenosis. The main instrument used in inside-out i.e., under ligamentum flavum decompression approach is endoscopic Kerissson Rongeurs to remove the ligamentum flavum and bony lamina together piecemeal, to gain early access to the epidural space in the procedure. While outside-in i.e., over the top decompression approach requires endoscopic drilling of lamina and medial facet leaving the ligamentum flavum intact in order to protect spinal cord from endoscopic drill. Both authors highlighted the pros and cons of their technique. Most surgeons however do a hybrid of both techniques hence it is a theoretical proposition for inside-out versus outside-in technique in lumbar spine. However the authors felt that in the case of thoracic OLF decompression performed with TE-ULBD technique, outside-in en bloc approach is preferable to reduce complications [5,6].

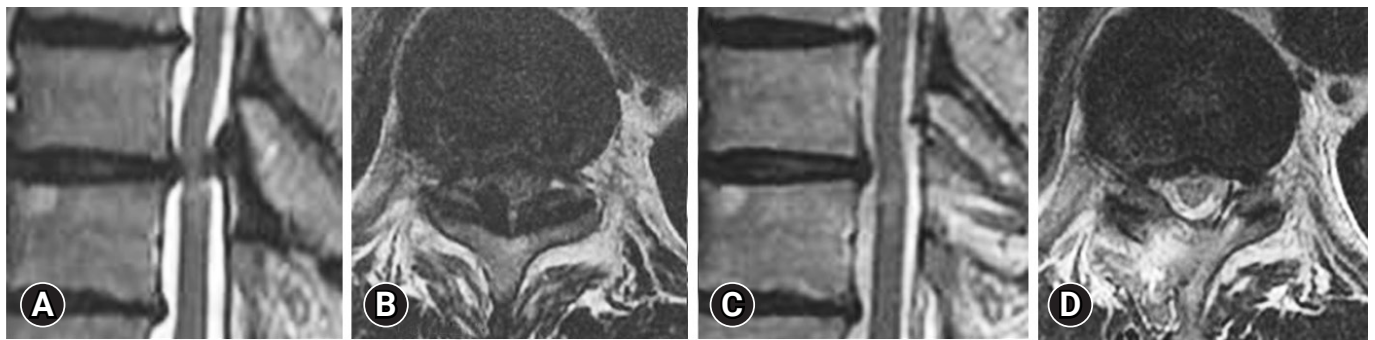
## Dangers and Potential Complications

Both under the ligamentum flavum and over the top decompression of ligamentum flavum approaches, the common complications are dura tear, neck pain/headache due to water irrigation pressure and incomplete decompression [18]. Dura tear can happen in 3% to 10% of lumbar cases with a higher dura tear complication rate in thoracic spine [4]. We found in our series there is dura tear rate of 3.3%. Small incidental durotomy can be repaired by patch blocking repair technique using gelfoam and tachosil [15]. Neckache and headache can be prevented by limiting the duration of surgery with high irrigation pressure. Optimal irrigation pressure is in the range of 25–45 mmHg with the mean of 30 mmHg [11,19]. Incomplete decompression is a common risk in any decompression surgery. The steep learning curve in endoscopic spine surgery is one of the reason for these complications [8,17]. Spinal instability is a potential complication despite studies showed that endoscopic surgery may preserve more facet joints and potentially lower the risk of instability [16,20], more long term data is required to demonstrate the role of spinal endoscopy in preservation of facet joint. Small wounds and conservation of soft tissue in TE-ULBD may decrease infection risk compared to open surgery. Endoscopic decompression has higher risk of incomplete decompression compared to open decompressive surgery, we

**Table 2.** Radiological parameters with the MRI axial cut cross-sectional area at the upper, middle, and lower disc level in TE-ULBD

Radiological parameters	TE-ULBD (mean and range) (mm <sup>2</sup> )
Preoperative MRI axial-cut cross-sectional area upper disc level spinal canal (mm <sup>2</sup> )	207.8 (70–911)
Preoperative MRI axial-cut cross-sectional area middle disc level spinal canal (mm <sup>2</sup> )	171.9 (55–332.8)
Preoperative MRI axial-cut cross-sectional area lower disc level spinal canal (mm <sup>2</sup> )	220.1 (69.9–451)
Postoperative MRI axial-cut cross-sectional area upper disc level spinal canal (mm <sup>2</sup> )	265.4 (100–512.7)
Postoperative MRI axial-cut cross-sectional area middle disc level spinal canal (mm <sup>2</sup> )	261.8 (101–504.4)
Postoperative MRI axial-cut cross-sectional area lower disc level spinal canal (mm <sup>2</sup> )	285 (102–529.5)

TE-ULBD: uniportal thoracic endoscopic unilateral laminotomy with bilateral decompression using the single block resection technique, TOL: thoracic open laminotomy with bilateral decompression, MRI: magnetic resonance imaging.



**Figure 3.** (A, B) Right T7/8 sagittal and axial MRI cut with thoracic ossified ligamentum flavum causing spinal cord compression. (C, D) Corresponding sagittal and axial cut with decompression by right T7/8 thoracic endoscopic unilateral laminotomy with bilateral decompression. MRI: magnetic resonance imaging.

**Table 3.** Comparative data of preoperative and postoperative clinical and radiological parameters in TE-ULBD

Comparative data of preoperative and postoperative clinical and radiological parameters in TE-ULBD	Mean	SD	p-value
Change in preop VAS–postop 1 wk VAS	–3.95	1.49	< 0.001**
Change in preop VAS–postop 6 mo VAS	–4.95	1.7	< 0.001**
Change in preop VAS–postop final VAS	–5.2	1.8	< 0.001**
Change in preop ODI–postop 1 wk ODI	–33.8	9.05	< 0.001**
Change in preop ODI–postop 6 mo ODI	–40.12	10.38	< 0.001**
Change in preop ODI–postop final ODI	–41.92	11.26	< 0.001**
Change in postop JOA–preop 1 wk JOA	1.19	0.92	0.002*
Change in postop JOA–preop 6 mo JOA	1.59	1.78	< 0.001**
Change in postop JOA–preop final JOA	1.95	1.4	< 0.001**
Change in upper end plate spinal canal MRI CSA in axial cut (postop MRI–preop MRI) (mm <sup>2</sup> )	57.62	50.6	0.002*
Change in mid-disc spinal canal MRI CSA in axial cut (postop MRI–preop MRI) (mm <sup>2</sup> )	89.86	55.93	< 0.001**
Change in lower end plate spinal canal MRI CSA in axial cut (postop MRI–preop MRI) (mm <sup>2</sup> )	64.93	60.91	< 0.001**

TE-ULBD: thoracic endoscopic unilateral laminotomy bilateral decompression, preop: preoperative, postop: postoperative, VAS: visual analog scale, ODI: Oswestry Disability Index, JOA: Japanese Orthopaedic Association, CSA: cross-sectional area.

have a case of incomplete decompression which required revision TE-ULBD. With experience and intraoperative CT scan, we can potentially reduce the rate of inadequate decompression. The risk of devastating neurological deficit in thoracic spinal decompression is a dreaded complication. We have one case of incomplete recovery from paralysis. Ruetten et al. [21], Kim et al. [5], and Wu et al. [6] showed lower risk in neurological deficit in their series of Thoracic endoscopic decompression, however

more studies are required to show reproducibility of their techniques.

In our cohort of patients who underwent the “outside-in approach” TE-ULBD, they demonstrated statistically significant improvement clinically and radiologically at various time point of follow up, with a relatively low rate of complications of complications of 5.4% (Figure 3).

## CONCLUSION

Thoracic Endoscopic Unilateral Laminotomy Bilateral Decompression Outside-In Technique could achieve good clinical outcomes and low rate of complications in our cohort of patients.

## NOTES

### Ethical statements

**Ethical approval:** All procedures performed in studies involving human participants were in accordance with the ethical standards of the Nanoori Hospital's Ethics Committee and the national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Consent from patients:** All patients had given their informed consent for photographs, videos, and images for publication.

**Informed consent:** Informed consent was obtained from all individual participants included in the study.

### Conflicts of interest

No potential conflict of interest relevant to this article.

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# Unilateral Biportal Endoscopic Decompression for Thoracic Spinal Stenosis

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In conventional thoracic laminectomy, postoperative complications such as dural tears, cerebrospinal fluid leakage, postoperative infection, and iatrogenic spinal cord injury are relatively common. To address these issues, unilateral biportal endoscopy (UBE) techniques for thoracic laminectomy have been developed and published, demonstrating various advantages over conventional thoracic laminectomy with satisfactory clinical results. In comparison to conventional thoracic laminectomy, the UBE decompression technique with the unilateral approach and bilateral decompression (ULBD) appears to be safe and effective for treating thoracic ossified ligamentum flavum (OLF) or thoracic spinal stenosis. Thoracic ULBD by UBE preserves the paraspinal muscle and ligament that would otherwise be resected during the conventional posterior approach, and it has the added benefit of reducing back pain and muscle atrophy. This manuscript covers the technical aspects of UBE implementation using thoracic ULBD in patients with thoracic OLF or thoracic spinal stenosis, the indications and benefits of this procedure, and tips for preventing complications. With a review of previously published articles on thoracic laminectomy by UBE, we also summarize whether the procedure is safe and can prevent cord injuries.

**Key Words:** Endoscopy, Laminectomy, Minimally invasive surgical procedures, Spinal stenosis, Thoracic

## INTRODUCTION

Traditional thoracic laminectomy has been considered the gold standard for treating thoracic ossified ligamentum flavum (OLF) and thoracic spinal stenosis [1-3]; however, it has several drawbacks, including postoperative back pain and paraspinal muscle atrophy caused by posterior musculoligamentous and facet joint injury [4]. As a result, fusion surgery may be required in some cases to prevent postoperative instability [5]. In a conventional thoracic laminectomy, postoperative complications such as dural tears, cerebrospinal fluid leakage, postoperative infection, and iatrogenic spinal cord injury are relatively common [6,7]. The clinical outcomes of a conventional technique for thoracic OLF or thoracic spinal stenosis are frequently un-

satisfactory and comorbid [3,8].

To address these issues, unilateral biportal endoscopy (UBE) techniques for thoracic laminectomy have been developed and published by some studies, demonstrating various advantages over conventional thoracic laminectomy and reporting competent clinical results [9,10]. For lumbar spinal stenosis, the concept of unilateral laminectomy for bilateral decompression (ULBD) has been successfully managed [11]. The ULBD using UBE in the treatment of thoracic OLF or thoracic spinal stenosis is also being investigated. In comparison to conventional thoracic laminectomy, the UBE technique for thoracic pathology may provide appropriate decompression with technical advantages and fewer complications, such as minimal musculoligamentous injury or facet joint destruction and minimal

spinal cord manipulation [9,10]. Furthermore, the endoscope and surgical instruments can be moved independently, making the operation safer and more effective than other endoscopic techniques [12].

Present manuscript has covered technical aspect of UBE decompression of thoracic OLF and thoracic spinal canal stenosis with its indications, advantages and tips to prevent complications. With a review of previously published articles on thoracic laminectomy by UBE, we also summarized whether the procedure is safe and can prevent cord injuries.

## INDICATIONS

When conservative treatment fails or the patient's neurological condition worsens, surgical treatment of thoracic ULBD by UBE is recommended. The following are the indications and contraindications for thoracic ULBD by UBE: 1) Thoracic spinal stenosis; 2) OLF; 3) Synovial cysts. Contraindications of thoracic ULBD by UBE are as follows: 1) Central disc herniation; 2) Severe ossified posterior longitudinal ligament (OPLL); 3) Spinal tumor; 4) Instability of the spinal column; 5) High-grade deformity; 6) Fused/tuberos type OLF, Severe thoracic stenosis or severe dural ossification; because of risk and technical challenge.

## SURGICAL PROCEDURE

### 1. Anesthesia and Position

Patient is placed prone on a radiolucent table after general anesthesia and intraoperative neurophysiological monitoring. Right-handed surgeons prefer the left-side approach because it facilitates bone work. It is recommended that the working portal for surgical instrument manipulation be used with the dominant hand. The scopic portal for endoscopic viewing, on the other hand, is used with the non-dominant hand.

### 2. Surgical Instruments

Most of the surgical instruments used in thoracic decompression by UBE are comparable to those used in other UBE procedures. This technique requires a diamond drill and a 1 mm Kerrison rongeur. A 0-degree scope is typically utilized, but a 30-degree scope is necessary to approach a centrally located thoracic disc herniation. Hook radiofrequency probe is used for coagulation of focal epidural vessels. Using pressure pump systems is not preferred as saline can be sufficiently infused

by gravity, which is enough to achieve a clear view while minimizing epidural bleeding. The proper height of the fluid back is about 40–60 cm from the patient's back.

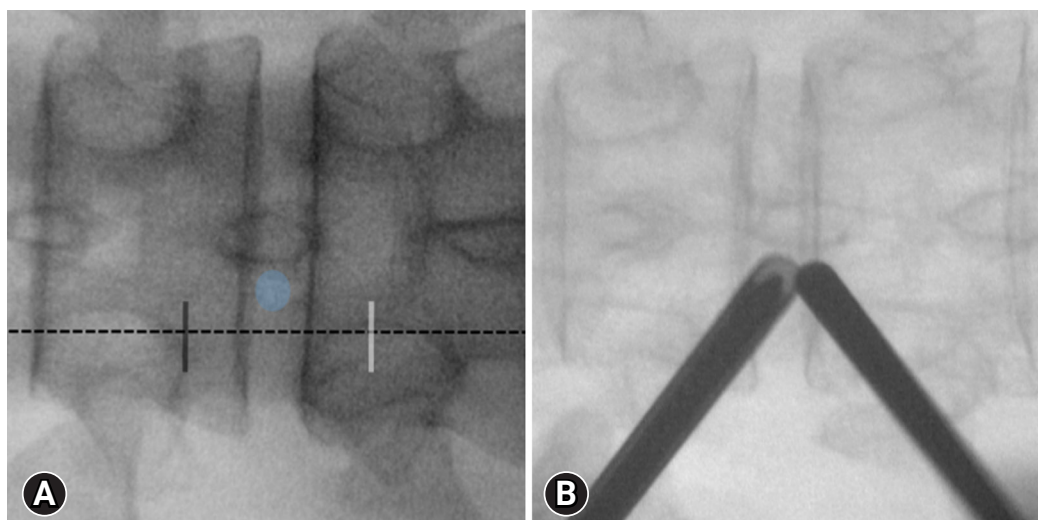
### 3. Skin Markings and Creating Portals

After positioning the patient, the inferior endplate line of the upper vertebral body is paralleled using C-arm fluoroscopic guidance. The docking point, the lower part of the cranial lamina, is confirmed using fluoroscopy's anteroposterior (AP) view. Two skin incisions, approximately 3 cm apart, are made on the medial margin of the proximal and distal pedicle, centered at the docking point (Figure 1A). A caudal skin incision is made for the working portal. And a cranial incision is made for the scope portal. A series of dilators are sequentially inserted via the working portal under fluoroscopic guidance, and an endoscope sheath is inserted through the scope portal to the docking point. The dilator tip and endoscopic sheath are triangulated over the docking point, and AP and lateral fluoroscopy are used to ensure proper positioning (Figure 1B).

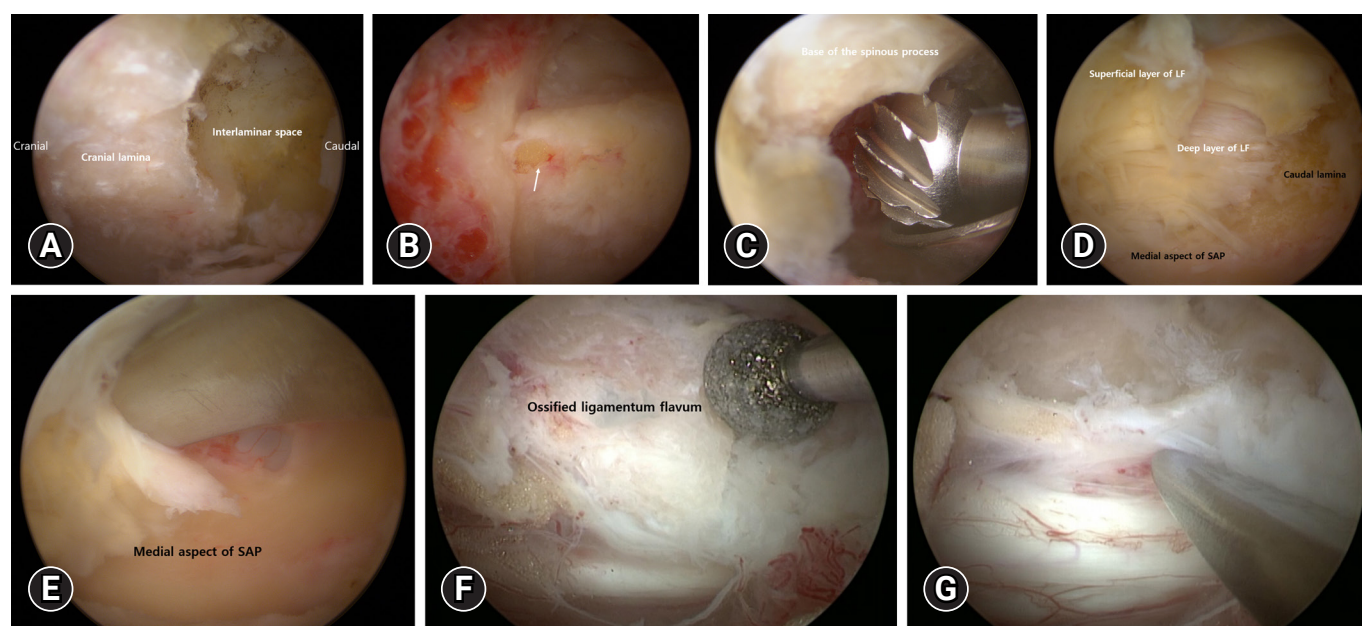
### 4. Bone Working

The lower part of the cranial lamina and interlaminar space are identified after soft tissue is removed with a radiofrequency (RF) probe (Figure 2A). Subsequently, cranial lamina is resected with the help of burr or Kerrison rongeur from caudal to cranial direction to expose ligamentum flavum (LF). At this point, it is critical to avoid burr or Kerrison rongeur compression of the LF. The midline gap of the LF, which serves as an anatomical landmark for midline orientation (Figure 2B). Cranial bone work is performed up to the anatomical landmark of the cranial end of the LF. To prevent cord injury while removing the lamina, the LF is used as a defender until the bone work is finished.

When performing a contralateral bone working via a sublamina approach, contralateral lamina and the base of the spinous process is drilled to allow enough space on the contralateral side (because the base of the spinous process interrupts the movement of the surgical instruments and the endoscope) (Figure 2C). The medial part of the facet joint is partially removed after a wide laminectomy to decompress both sides. The lateral end of the laminectomy overlaps the medial aspect of the facet joint, which is preserved to prevent instability.



**Figure 1.** Fluoroscopic anteroposterior (AP) view of the docking point and skin incision at T10-T11 levels. The docking point (blue circle) is the lower part of the cranial lamina. Two skin incisions (working portal: white line; scopic portal: black line) are made approximately 3 cm apart, with the center as the lower part of the cranial lamina at the midline of the proximal and distal pedicles (dotted line) (A). Triangulation of the dilator and the endoscopic sheath above the docking point on a fluoroscopic AP view (B).



**Figure 2.** Serial sequence endoscopic images of thoracic ULBD by UBE. The surgical anatomy is first noted at the lower part of the cranial lamina, and the interlaminar space (A). Anatomical landmark for midline orientation. The white arrow indicates the midline gap of the ligamentum flavum (LF) (B). The base of the spinous process should be removed to provide enough space for safe decompression (C). Exposure of the upper portion of the caudal lamina and medial margin of the superior articular process after removal of the superficial layer of the LF (D). Removal of the paper-thin, translucent medial part of superior articular process using double-ended elevator (E). The OLF is ground into a thin form using a diamond drill (F). The thinned OLF can be detached from the dural sac using a double-ended elevator (G). ULBD: unilateral approach and bilateral decompression, UBE: unilateral biportal endoscopy; OLF: ossified ligamentum flavum.



## 5. Removal of Ligamentum Flavum

Following bone work, a double-ended elevator and pituitary forceps are used to remove the superficial layer of LF from the caudal lamina (Figure 2D). Following that, a landmark for lateral decompression is identified as the junction between the caudal lamina and the medial aspect of the superior articular process (SAP) (Figure 2D). To prevent the Kerrison rongeur from compressing the spinal cord beneath the bony structures, the caudal lamina and the medial part of the SAP are ground thin with a diamond drill. The LF is carefully separated after thinning with a 1 mm Kerrison rongeur or double-ended elevator that continues along the medial aspect of the SAP, allowing En-block removal of the deep layer of LF (Figure 2E). The procedure for removing the contralateral LF is the same as described above.

In the case of OLF, the OLF is identified by removing the LF's superficial layer. With the use of diamond drill OLF is thinned out as much as possible (Figure 2F). The remaining thinned OLF was separated from the dura with a double-ended elevator and carefully removed one at a time with small-sized pituitary forceps (Figure 2G). If the dura mater and OLF are not separated by adhesions or dural ossification, the calcified portion of the OLF is thinned, leaving a thinned OLF. The floating method is known to prevent dural tear and cord injury. The decompression is completed at the medial margins of the pedicle and lateral margin of the thecal sac. Finally, a free-floating dura indicates adequate decompression under endoscopic guidance.

## 6. The Final Checking Point

The adhesion of the OLF to a dura sac, which can lead to the risk of a dura tear, a complication of a small dura tear, can be managed by applying a fibrin collagen patch (TachoSil) and bed resting for 7 days. If the dura tear is large enough that the

fibrin collagen patch cannot cover it, the dural tear can be repaired directly through dural suturing or microscopic surgery. To address this complication, preoperative CT and MRI should be checked to look for dural ossification within the OLF.

To prevent postoperative hematoma, a Jackson-Pratt surgical drain (100 mL) is inserted via the working portal after the operation. Inserting the Jackson-Pratt drain deeply should be done with caution because the tip of the drain can cause cord injury. Postoperative MRI should be checked at the second day after surgery. Jackson-Pratt surgical drain is removed 1 or 2 days postoperatively.

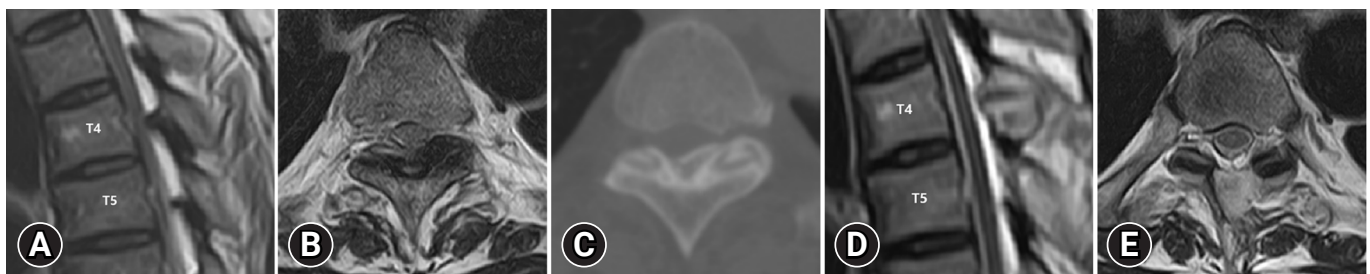
## RESULTS

### 1. Case 1: Ossified Ligamentum Flavum

A 57-year-old man presented with spastic paraplegia, Nurick's grade 4 that had been present for 12 months. Preoperative MRI and CT showed bilateral OLF compressing the cord at the T4-T5 level (Figure 3A-C). ULBD by UBE was performed on the left side at the T4-T5 level. The operation time was about 65 minutes. The OLF was removed, and the thecal sac was decompressed completely. Postoperative MRI and CT scans confirmed complete decompression (Figure 3D, E). Following a 4-month follow-up after, both lower extremity weakness was restored to grade 5. His neurologic symptoms were improved to Nurick's grade 0.

### 2. Case 2: Thoracic Spinal Stenosis

For 9 months, a 71-year-old man presented with bilateral lower extremity weakness with compressive myelopathy from thoracic spinal stenosis at T11-T12 since 9 months. For three months, he received conservative treatment. His symptoms, however, did not improve and worsened. His Nurick's grade



**Figure 3.** Images of a 57-year-old man with ossified ligamentum flavum at the T4-T5 level. Preoperative MRI and CT shows ossified ligamentum flavum at the T4-T5 level (MRI sagittal: A, axial: B, CT axial: C). Postoperative axial T2-weighted MRI shows complete removal of ossified ligamentum flavum (sagittal: D, axial: E). MRI: magnetic resonance imaging, CT: computed tomography.

was 3. Preoperative MRI scan showed T11-T12 thoracic spinal stenosis (Figure 4A, B). At T11-T12, bilateral hypertrophic LF compressed the spinal cord. The operation time was about 55 minutes. MRI scans after surgery revealed adequate spinal cord decompression at the T11-T12 level (Figure 4C, D). The neurological symptoms significantly were improved to Nurick's grade 0.

## DISCUSSION

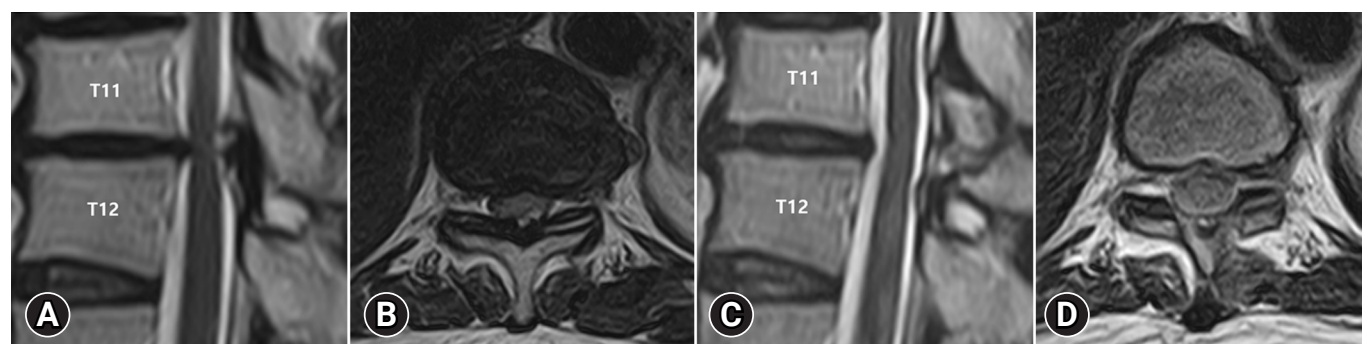
Due to a low canal-to-spinal cord ratio, thoracic kyphosis pushing the spinal cord anteriorly, and poor blood supply in the watershed area, the thoracic spinal cord is vulnerable. Excessive manipulation of the thoracic spinal cord with surgical instruments increases the risk of neurological deterioration; thus, thoracic decompression should be performed with caution to avoid unintended spinal cord injury [13]. As a result, the goal of thoracic decompression is to achieve adequate decompression with minimal spinal cord manipulation while avoiding paraspinal muscle/facet injury.

The thoracic ULBD by UBE has several advantages over conventional laminectomy for OLF or thoracic spinal stenosis: (1) The combination of an angled field of view and freedom of movement allows enough space and minimal spinal cord manipulation [12]. This can aid in adequate decompression and improve clinical outcomes while avoiding the complications associated with conventional thoracic laminectomy. (2) While operating under continuous saline irrigation, UBE provides a familiar operative view and high magnification/clearing availability [10]. Furthermore, this technique can achieve precise OLF removal while lowering the risk of dural tear or cord injury, which is identified under endoscopic view. (3) When the precise route for the endoscope and surgical instruments is determined, this surgery can be completed effectively with less

disruption of the facet joint and musculoligamentous complex than conventional thoracic laminectomy [10].

UBE has published two articles on posterior thoracic decompression [9,10]. One article was a technical note about removal of the OLF by UBE. Kang et al. [9] described the surgical steps of UBE-assisted posterior thoracic decompression, including a discussion of the indications, benefits, complications, and ways to avoid complications. Another paper described the surgical technique and provided preliminary clinical results. Deng et al. [10] demonstrated posterior thoracic decompression by UBE in 14 patients with single-level thoracic OLF. With an average follow-up of 15.4 months, they demonstrated a statistically significant improvement in mJOA score ( $p < 0.001$ ) and VAS ( $p < 0.001$ ) with UBE. Five cases of perioperative complications were among the complications (one patient with cerebrospinal fluid leakage, two with headaches and neck pain, and two with hyperalgesia of lower limbs). According to two studies, UBE techniques are effective and safe for treating thoracic OLF.

To avoid iatrogenic spinal cord injury when performing thoracic ULBD by UBE, several principles must be followed. Following recommendations are based on the prevention of neurological deterioration. 1) When bone working is performed bilaterally, care must be taken to cover the spinal cord while preserving the LF. 2) The base of the spinous process must be removed sufficiently to ensure adequate working space, especially for contralateral decompression. 3) The placement of the surgical instrument into the stenotic spinal canal must be avoided due to the risk of cord injury. As a result, it is safe to thin the bone structure with a diamond burr. The LF and residual lamina can be removed with the double-ended elevator, and the paper-thin residual lamina can be easily removed. This technique allows for En-block resection of the LF's deep layer without causing cord compression or dural tear. 4) Use



**Figure 4.** Images of a 71-year-old man with thoracic spinal stenosis at the T11-T12 level. Preoperative MRI shows thoracic spinal stenosis and compression of the cord at the T11-T12 level (MRI sagittal: A, axial: B). Postoperative axial T2-weighted MRI shows sufficient decompression of the thoracic spinal stenosis (MRI sagittal: C, axial: D). MRI: magnetic resonance imaging.

RF probes with caution near neural structures. Surgeons must take special care when using RF probes around the spinal cord to avoid using them on neural structures with low RF power. 5) Because using Kerison Longeur to remove the OLF is dangerous, a diamond drill is used to drill through the OLF into a translucent shape. 6) If removing the OLF is difficult with dural ossification or severe adhesion, it is safe to leave the thinned portion of the OLF in place using the floating method. The dural opening must be completely sealed with a fibrin collagen patch after the OLF has been floated. 7) Fluid-related complications includes headache, neck stiffness, seizures, and cord injury [9,10]; as UBE is a fluid-mediated surgery, it is critical to monitor fluid drainage, the complications caused by fluid can be avoided by using a semi-tubular retractor. 8) Because of the technical difficulties, novice surgeons should avoid performing UBE on patients with fused or tuberous-type OLF, severe thoracic stenosis, severe OPLL. As it has clinical characteristics and a poor prognosis. 9) The thoracic cord is vulnerable due to the low canal-to-cord ratio, thoracic kyphosis that pushes the cord anteriorly, and insufficient blood supply in the watershed zone. Therefore, somatosensory and motor-evoked potentials are used to prevent cord injury.

To avoid postoperative hematoma when performing thoracic ULBD by UBE, several principles must be followed. Bone bleeding should be waxed immediately to reduce the risk of postoperative hematoma. Particular attention should be provided to epidural vessel bleeding during LF resection. Prior to LF resection, the use of the RF probe and hemostatic agents (Gelfoam or WoundClot) are sufficient to control bleeding. To prevent postoperative hematoma, the Jackson-Pratt surgical drain (100 mL) should be placed through the working portal for 1 or 2 days.

Although UBE has grown in popularity in recent years, thoracic ULBD via UBE is technically difficult and has the potential for significant outcomes. As a result, we recommend that thoracic ULBD by UBE be used only after the surgeon has sufficient experience with UBE for lumbar surgery. Due to safety and technical challenges, novice UBE surgeons should avoid challenging cases such as fused-type or tuberous-type OLF, severe thoracic stenosis or severe dural ossification. To avoid complications, the surgeon must recall anatomical landmarks, surgical techniques, and his or her level of comfort and competence with the UBE method.

## CONCLUSION

In conclusion, the UBE decompression technique with uni-

lateral approach and bilateral decompression appears to be safe and effective for treating thoracic OLF or thoracic spinal stenosis. Thoracic ULBD by UBE preserves the paraspinal muscle and ligament that would otherwise be resected during the traditional posterior approach, and it has the added benefit of reducing back pain and muscle atrophy. Although thoracic ULBD by UBE is not currently the standard treatment for thoracic OLF or thoracic spinal stenosis, this technique has the potential to be more widely used in the future.

## NOTES

### Ethical statements

Not applicable.

### Conflicts of interest

No potential conflict of interest relevant to this article.

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# Destandau's Approach to the Cervical and Thoracic Spine

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**Objective:** Destandau's endospine technique was initially described for lumbar disc herniation and was later applied for lumbar spinal stenosis. Favorable outcomes have been reported with this technique for lumbar degenerative pathology. This article attempts to review the literature and define the scope of Destandau's technique in cervical and thoracic pathologies.

**Methods:** A literature search for the keywords "Destandau" and "endospine" was performed in the PubMed, Cochrane, Scopus, Embase, and MEDLINE databases. The review was conducted according to the Scale for the Assessment of Narrative Review Articles (SANRA) tool.

**Results:** In total, 91 studies were found, out of which three studies employed Destandau's endospine technique for cervical and thoracic pathologies. Three book chapters describing the Destandau technique in cervical pathology and intradural tumor excision were also included in the review. The technique has been successfully employed by various authors for an anterior or posterior cervical approach to disc herniation, cord decompression, and excision of intradural extra-medullary lesions of the spinal canal. No studies mentioned using the Destandau technique for thoracic disc herniation, traumatic fractures, or ossified ligamentum flavum decompression.

**Conclusion:** Destandau's endoscopic technique has been applied successfully in anterior and posterior cervical approaches for cervical disc herniation, myelopathy and intradural tumors, and its advantages include less pain, minimal muscle damage, shorter hospital stays, and the preservation of spinal stability/segment mobility. Further studies comparing various techniques would help choose the most patient-friendly technique for specific pathologies.

**Key Words:** Destandau technique, Endospine, Cervical disc, Intradural tumor, Endoscopic spine surgery, Minimally invasive spine surgery

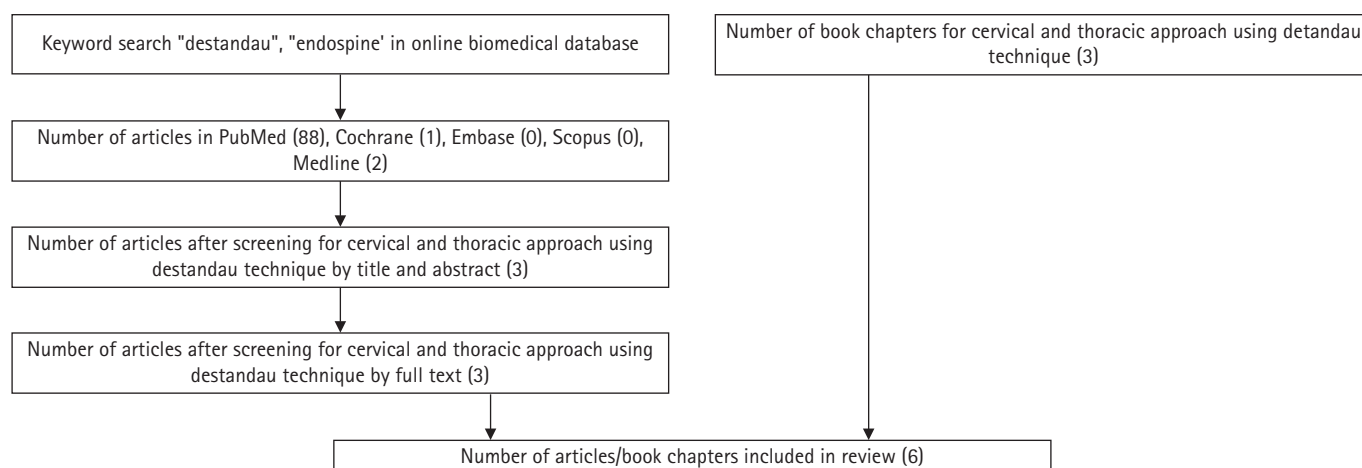
## INTRODUCTION

Dr Jean Destandau, MD, neurosurgeon from Bordeaux, France, developed a technique of endoscopic spine surgery in 1993 [1-3]. The Destandau's technique of mobile endospine tube has been largely employed in lumbar disc herniation and lumbar spinal stenosis with favorable outcomes [4-7]. The technique is based on the principle of laparoscopic triangulation between an endoscope and suction with working instrument. Various approaches to the cervical and thoracic spine ranging

from open, microscopic tubular, percutaneous, full endoscopic, biportal endoscopy techniques are available. This article attempts to review and define the scope of Destandau's technique for cervical and thoracic pathology.

## MATERIALS AND METHODS

A literature search with keywords "Destandau", "Endospine" was performed in PubMed, Cochrane, Scopus, Embase, MEDLINE databases (Figure 1). The quality of narrative review was



**Figure 1.** Flowchart of the literature search for the use of Destandau's technique for cervical and thoracic approaches.

performed using Scale for the Assessment of Narrative Review Articles (SANRA) tool [8].

### Destandau's Technique – Surgical Method

The system consists of an elliptical outer tube which is docked at the site of pathology and an inner tube/working insert which has four in-built channels for the surgeon to work – one for the scope, one working channel for instruments, one for suction and last one for nerve root retractor. The inner tube/working insert fits into the outer tube with a tightening screw or a ratchet-type lock. There is an inherent telescoping movement in between these tubes. The system is compatible with a zero-degree, 18 cm long rigid endoscope. The tube can be angled and rotated in all directions to provide mobility. The channels for endoscope and suction are at an angle of 12 degrees to the working channel for instrument. Because of this angle, one can use 0-degree endoscope as an angled endoscope. This helps in minimizing the fogging of endoscope tip.

Once the outer tube is pushed in between the muscles laterally and the spinous process medially, and if the muscles are not separated off the midline carefully, then muscles will intrude inside the outer tube. The surgeon uses two gauze pieces to retract the muscles laterally. The cranial gauze piece is pushed over the cranial lamina and the caudal gauze piece is pushed over the caudal lamina. The gauze pieces must be attached with a thread so that one will not forget the gauze piece by mistake. Once the soft tissues are cleared over the interlaminar area after docking the outer tube with the help of disc forceps or bipolar coagulation, the inner tube is docked onto the outer tube and endoscopic procedure is started. The suction is used with the left hand and working instrument is in the right

hand. With suction in the left hand, the surgeon can move the whole system in medial, lateral, cranial, and caudal direction. The same movements are possible with instrument in the right hand (Figure 2).

## RESULTS

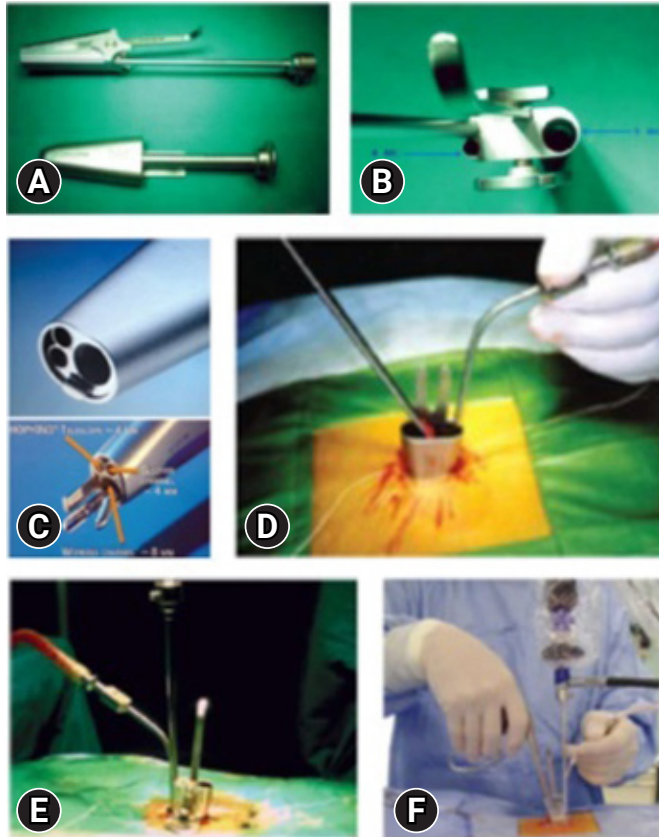
A total of 91 studies were found, out of which 3 studies [9-11] were found to have employed the Destandau endospine in cervical and thoracic pathology. Three book chapters on Destandau technique in cervical pathology and intradural tumor excision were also included in the review [12-14]. All the studies included were limited to case report or case series (level 4 evidence).

## DISCUSSION

### 1. Destandau's Technique in Cervical Spine

The anterior approach to the cervical spine for discectomy was described in 1955 by Robinson and Smith [15]. Currently, anterior cervical discectomy and fusion is regarded as the gold standard surgical option for cervical disc herniation. However, this technique can be accompanied by considerable approach [16-19] and fusion-related complications [20-22]. Mostofi and Khouzani [9] described anterior cervical foraminotomy by Destandau technique (Figure 3) to limit surgical trauma, avoid fusion, preserve motion segment and enhance post-operative recovery. More than 400 patients underwent surgery using this technique in the Endoscopy Center of Spine Surgery in Bordeaux from 2002 to 2014. They felt the visual field in anterior cervical foraminotomy by Destandau technique is broad and

depending on the workability of endospine an adequate access even to two cervical levels is possible. The nerve root is decompressed under direct vision and unlike conventional anterior decompression under the microscope, the surgeon does not



**Figure 2.** (A) Inner and outer tubes. (B) Inner tube view of ports from above. (C) Different channels for suction, the endoscope, working instrument, nerve root retractor. (D) Outer tube placed with two gauze pieces and a long thread. (E) Inner tube docked over the outer tube. (F) Outside view of suction in the left hand and instrument in the right hand, controlling the mobility of the tube.

need to stop and change the position of the surgical operating microscope. There is no need to maintain retraction on esophagus and carotids when the endospine tube is placed hence the risk of esophagus and carotid artery injury can be minimized.

Taran et al. [10] reported using Destandau technique to perform a transoral intralesional excision of C2 chordoma in a 44-year-old lady with prior C1-4 posterior fixation followed by post-operative radiotherapy. They reported no recurrence, metastasis or significant neural deficit at 3 years follow-up.

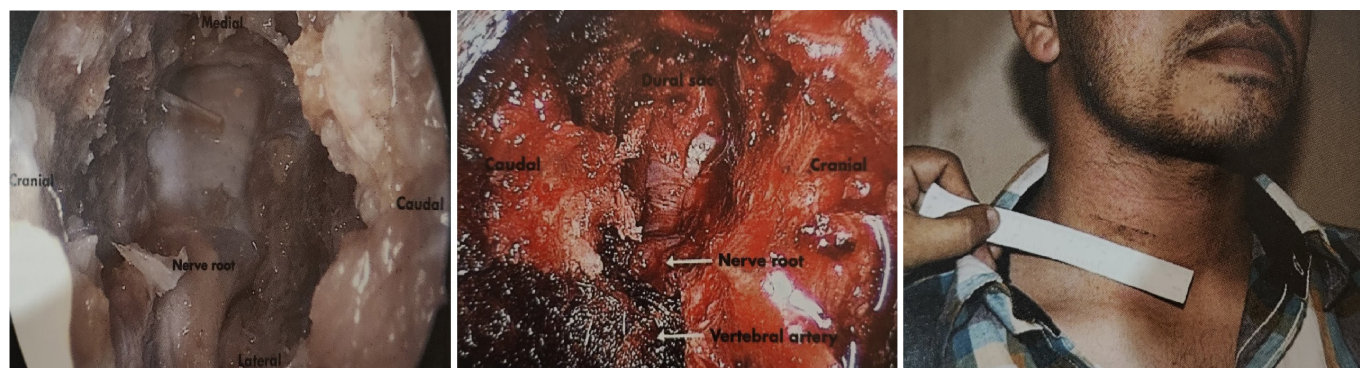
Endospine can be used for anterior cervical foraminotomy and partial vertebrectomy as described by Jho [23,24]. Rohidas [12] used Jho's Technique (Figure 4) through Endospine for anterior cervical foraminotomy, discectomy and cord decompression in 55 patients from 2006 to 2016 with excellent results in fifty-two, good in two, fair result in one patient. Dural puncture occurred in one patient which was sealed with muscle piece and fibrin glue; two patients developed Horner's syndrome; two patients developed transient recurrent laryngeal nerve palsy that recovered completely in 2–8 weeks period.

Rohidas and Destandau [13] also described Destandau technique (Figure 5) for posterior cervical laminoraminotomy and posterior endoscopic cervical canal decompression via unilateral approach in 30 patients from 2004 to 2016. He reports excellent results in 25 patients, 4 good and 1 fair result as per Macnab's criteria. One patient had a dural tear which was sealed with small muscle and fibrin glue. The author claims an advantage of less hospital stays, less post-operative pain with preservation of motion segment with equivalent efficacy in comparison to open procedures. They advised against posterior approach in cervical instability with deformity, symptomatic central disc hernia with myeloradiculopathy and diffuse ossification of posterior longitudinal ligament causing anterior cord compression.

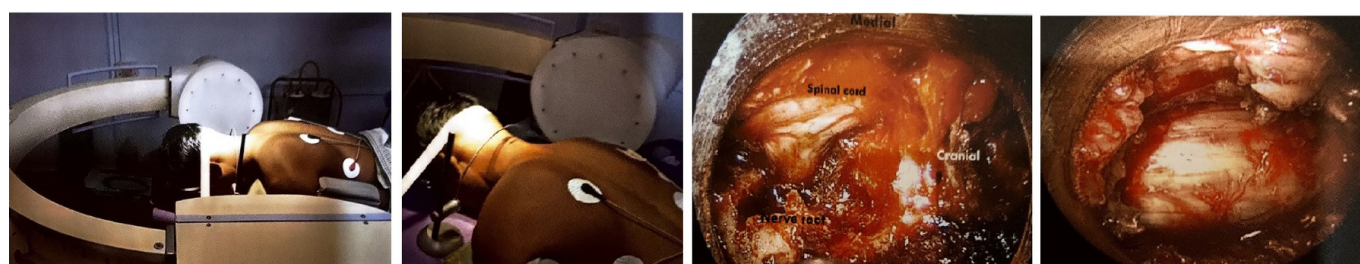


**Figure 3.** Cervical localization pin, X-ray level check, and clinical use of the localizing pin in a patient for the anterior approach.





**Figure 4.** The anterior Jho approach in a cadaver, anterior endospine approach for cord and root decompression, and clinical scar from the anterior endospine approach.



**Figure 5.** Patient positioning, using a localizing pin for the posterior approach, posterior lamino-foraminotomy, and posterior cord decompression.

## 2. Destandau's Technique in Thoracic Spine

The interlaminar approach for Thoracic Disc Herniation has been abandoned because of the high incidence of cord damage associated with the procedure [25]. Additionally, in the thoracic region, the window is very small or absent, meaning that more bone removal is required for entry into the canal. The sole indication for an interlaminar approach would be a migrated disc lying dorsal to the spinal cord [25].

We could not find any literature on Destandau Technique for decompression of thoracic ossified ligamentum flavum and traumatic dorsal fractures.

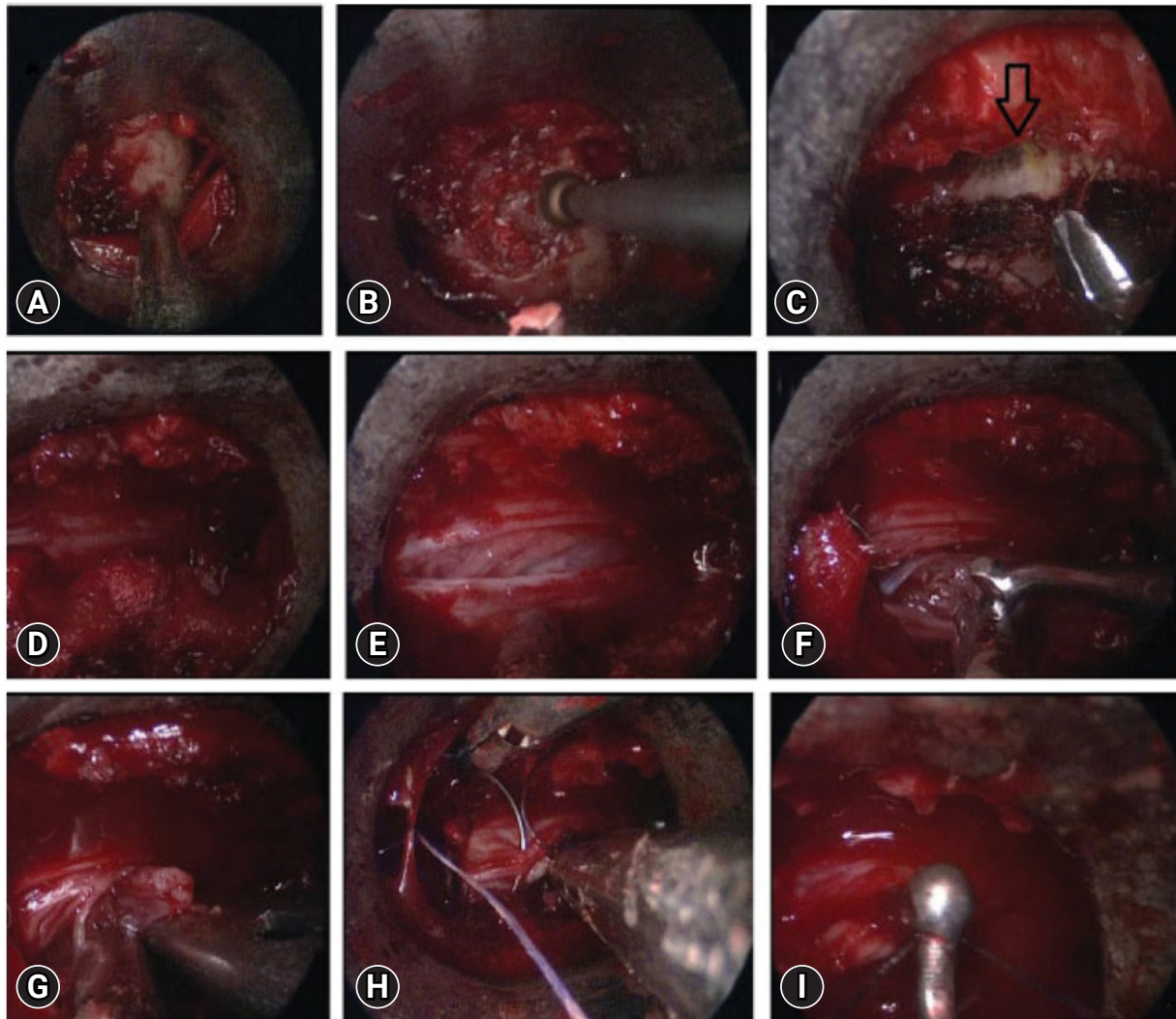
## 3. Destandau's Technique in Intradural Extramedullary Spinal Lesion

Posterior midline laminectomy has been successfully applied as the standard microsurgical technique for the treatment of spinal intradural pathologies. Minimally invasive approaches for intradural tumors have been found to be safe and effective [26-28]. Unilateral hemilaminectomy for intradural tumors using endoscopic assistance has been used successfully for intradural spinal tumors with preservation of musculoligamen-

tous attachments and posterior bony elements [29]. Parihar et al. [11] reported their experience of 18 cases using Destandau's technique (Figure 6). They included lesions extending up to two vertebral segments. There were 13 schwannomas and 5 meningiomas. All patients improved to normal neurologic functions (modified Frankel grade E) after surgery at follow-up except one patient who was wheelchair bound preoperatively, who also improved and became ambulatory and could walk independently without any support with normal bladder and bowel functions (modified Frankel grade D 3c). Rohidas and Destandau [14] described Destandau's technique (Figure 7) for intradural extramedullary spinal lesions in 17 cases from 2004 to 2016. Fourteen patients had neurofibroma at lumbar and thoracic level and three cases had meningioma. Sixteen patients recovered completely and one patient had partial recovery of spastic paraplegia. Closure of dura was achieved with 2 mm titanium anastoclips. No CSF leak or wound infection were noted in all patients.

Although endoscopic approaches have many advantages, they are also associated with some limitations such as difficulties in tumor localization, removal of a large tumor, primary dural suturing, control of bleeding, a steep learning curve, and difficulties in bimanual dissection. Improving endoscopic skill





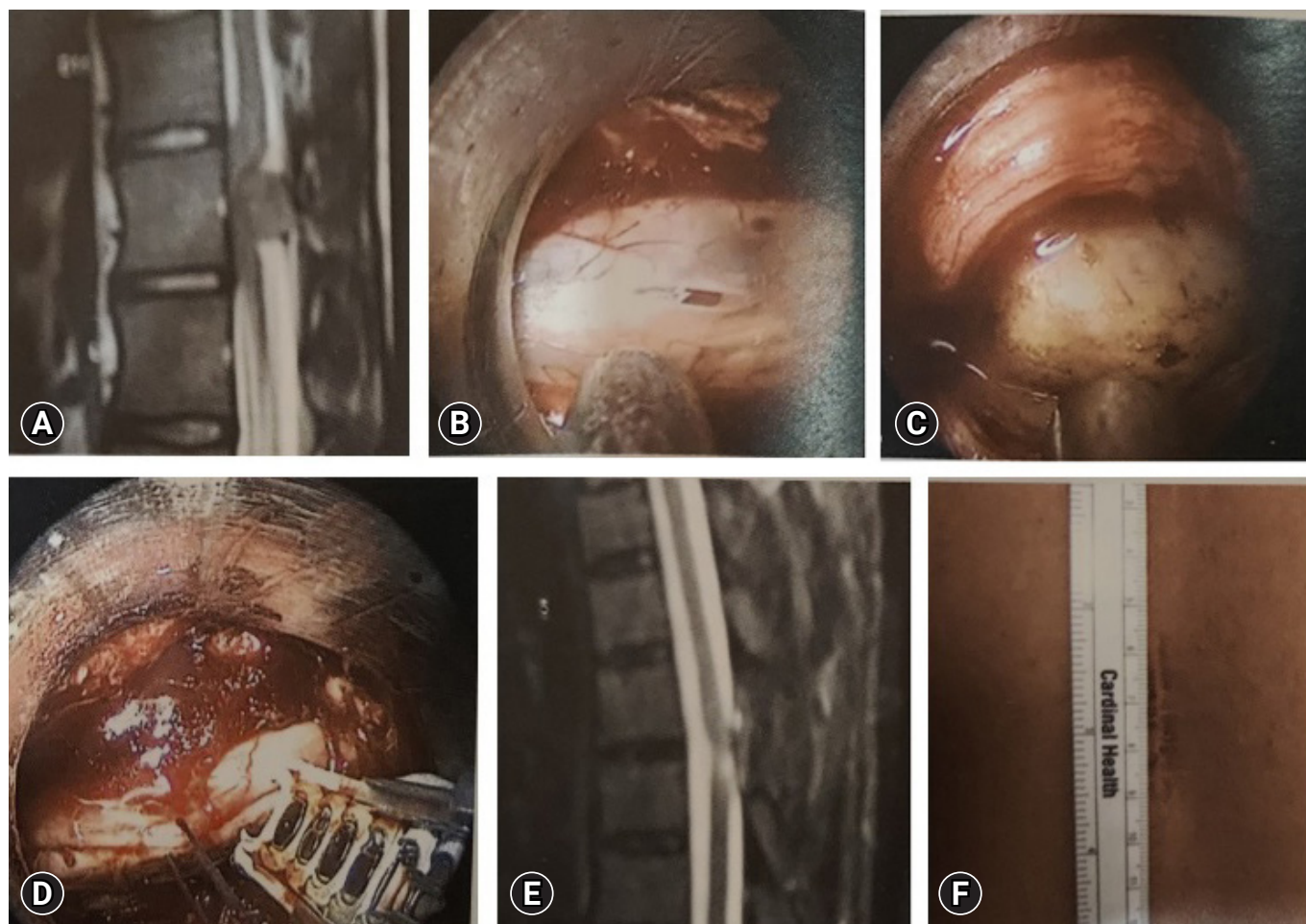
**Figure 6.** Endoscopic images showing exposure of the lamina (A), drilling of ipsilateral lamina (B), undercutting of the contralateral lamina (arrow) (C), exposure of the thecal sac after removal of bone and ligamentum flavum (D), dural incision (E), removal of the tumor using the bimanual technique (F, G), direct repair of the dura mater using a fine needle (H), and a knot pusher (I) for dural suturing.

using bimanual dissection, hemostasis, and suturing can be learned by attending live operative workshops, cadaveric dissection, watching operative videos, visiting other departments, and watching skillful neuroendoscopic surgeons [30].

#### 4. Destandau Technique Advantages, Limitations and Complications

The endospine technique can be applied at all spinal levels of degenerative spinal pathology – via anterior cervical, posterior cervical, posterior thoracic approach. It can be used in symptomatic disc herniations, spinal stenosis, intradural tumor excision/dural repair. It has also been utilized in debulking of

vertebral body tumor (axial chordoma) as reported by Taran et al. [10]. Being a mobile operating tube, it can be tilted and rotated in any direction to address more than one level through a single skin incision. A fixed microscopic system requires multiple tubes of various diameters and lengths depending on patient body fat, build and type of pathology to be addressed; leading to increase in operative inventory which is minimized by use of single endospine tube. This can be advantageous for setups in less developed areas and for travelling surgeons who can minimize the overall cost. Once the surgeon can overcome the learning curve, the contralateral over the top decompression can be performed under better visual control as compared to microscopic techniques.



**Figure 7.** (A) Preoperative magnetic resonance imaging (MRI) showing an intradural space-occupying lesion. (B) Endospine posterior approach. (C) Exposed tumor after durotomy. (D) Dural closure with 2-mm anastoclips. (E) Postoperative MRI showing total excision. (F) Endospine skin incision.

Destandau technique also has limitations as it utilizes a relatively larger skin incision as compared to full-endoscopic and biportal endoscopic techniques. The subperiosteal stripping of muscles done in order to dock the tube during the interlaminar approach can lead to more atrophic changes in the para-spinal muscles when compared to full endoscopic and biportal techniques. Repeated blood soiling of scope tip can be troublesome when the scope is advanced deeper into the field- this is not an issue in saline medium endoscopy. The system is only compatible with a zero-degree rigid endoscope whereas other endoscopic systems can employ zero degree, 15 degrees, 30 degrees endoscope to allow improved field of view. The system cannot be employed for performing lumbar fusions. As with any technique, there is a learning curve to be overcome initially to get proficient with the technique.

Complications like dural tear, nerve root injury, wrong level

surgery, inadequate decompression, recurrence, infection, facet overcutting, instability can occur as with any other open, microscopic and endoscopic techniques.

## 5. Study Limitations

All the studies using Destandau's technique for cervical and thoracic approach were case report and case series by various authors (level 4 evidence). There were no study comparing efficacy of Destandau's technique with different techniques like open, microscopic approach for cervical and thoracic pathology. The available literature for Destandau's technique for cervical and thoracic approach is very limited. Further studies focusing on comparing different open, microscopic and endoscopic techniques amongst each other would be helpful in deciding the best technique suited for a particular pathology.

## CONCLUSION

The endoscopic Destandau's technique has been applied successfully in anterior, posterior cervical approach for cervical disc herniation, myelopathy and intradural tumors with advantage of less pain, minimal muscle damage, less hospital stays and preservation of spinal stability/segment mobility. There is no literature mention of the technique being used for thoracic disc herniation, dorsal traumatic fractures or decompression of ossified ligamentum flavum. Further studies comparing various techniques among each other would help choose the most patient friendly technique for the particular pathology.

## NOTES

### Ethical statements

The patient data used in the article has already been cited and relevant references are mentioned; no additional patient data was used or updated to the already present literature. This being a narrative review article would not need any institutional committee approval.

### Conflict of interest

No potential conflict of interest relevant to this article.

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# Complications in Cervical and Thoracic Spine Surgery

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Minimally invasive surgery has continued to grow as an alternative approach to traditional open methods of treating cervical and thoracic spine pathologies, with similar efficacy, shorter hospitalizations and decreased tissue destruction. This manuscript presents a review of the literature and summarizes complications seen in cervical and thoracic spine surgery, focusing on different types of minimally invasive procedures. Overall, our review suggests that minimally invasive approaches have less severe complications than open approaches, and indicates the need for prospective studies to examine this finding further.

**Key Words:** Laminectomy, discectomy, foraminotomy, neurosurgery, endoscopy

## INTRODUCTION

Minimally invasive techniques for spinal surgery have emerged as alternatives to the traditional open approach and are associated with a similar efficacy and shorter hospital stays [1]. These techniques are especially beneficial given their ability to prevent damage to the crucial supporting musculature of the spine and to consequently preserve its structural integrity [2]. Additional benefits include a smaller incision, a reduction in intraoperative blood loss, and a reduced need for analgesics when compared to open surgery [3]. However, all surgeries, whether open or minimally invasive, carry an inherent risk of complications.

Open cervical spinal surgery in particular is associated with a variety of complications. From an anterior approach, these include dysphagia after mobilization of the trachea and esophagus during surgical exposure, dysphonia due to nerve injury, and surgical site infections. In addition, retropharyngeal hematomas, esophageal injury, vascular injuries, and damage to the cervical sympathetic change also occur, but are less common

[4]. More commonly a concern from a posterior approach, vertebral artery and cervical nerve root injuries can also occur [5,6].

Open thoracic spinal surgery is also traditionally associated with a variety of complications. From an anterior approach, injury to the great vessels is possible leading to hemorrhage as is damage to the thoracic duct leading to chylothorax [7]. Large exposures and lengthy surgeries often with the support of cardiothoracic surgeon can lead to significant post-operative pain, pneumothorax, pulmonary effusion, or pneumonia, all of which may further worsen the pulmonary status of a patient with impaired respiratory function [8]. From the posterior approach, misplaced pedicle screws may also damage the great vessels potentially leading to bleeding, thromboembolism, or pseudoaneurysm formation [9]. Spinal cord ischemia, nerve root injury, dural tear, and hematoma formation are also possible with both the anterior and posterior approaches [7].

Despite the known complications of open surgery involving the cervical and thoracic spine, complications associated with minimally invasive surgery (MIS) techniques remain unanswered. The present review seeks to identify potential com-

plications associated with cervical and thoracic spine surgery using the tubular, endoscopic tubular assisted, uniportal endoscopic, and biportal endoscopic surgical approaches.

## MATERIALS AND METHODS

### 1. Literature Search

Electronic searches were conducted using PubMed, Ovid Medline, and Cochrane Central Register of Controlled Trials (CCTR) from January 2012 until December 2022. In order to maximize the identification of relevant studies, searches were conducted by variably combining the terms: “biportal”, “micro-endoscopic”, “uniportal”, “cervical”, “thoracic”, “spine”, “surgery”, “complications”, and “minimally invasive” as either medical subject headings (MeSH) or keywords. Additionally, a search of the phrase “minimally-invasive cervical and thoracic spine surgery complications” was performed. The reference lists of all retrieved articles were further reviewed for any relevant studies. The titles and abstracts of the identified articles were then systematically assessed for any mention of minimally invasive tubular, endoscopic tubular-assisted, uniportal endoscopic, or biportal endoscopic surgery to the cervical or thoracic spine. The subsequent texts were then read in full for any mention of complications.

### 2. Selection Criteria and Data Extraction

Eligible studies for inclusion in the current review were those that included patients who underwent one of the four aforementioned MIS approaches for the treatment of a cervical and/or thoracic spine pathology with mention of complications. When institutions published studies with an overlapping patient population, the study with the larger patient cohort was selected. All publications were limited to those involving human subjects and written in the English language. Case-reports, cohort studies, and randomized control trials were included; abstracts, conference presentations, editorials, expert opinions, and review articles were excluded. All data related to complications following one of the four minimally invasive operative approaches was extracted from article texts and tables.

## RESULTS

### 1. Literature Search

A total of 520 references were identified after an electronic

database search through PubMed, Ovid Medline, and CCTR.

After exclusion of duplicate references, the titles and abstracts of 485 potentially relevant articles were reviewed, and 371 were excluded based on relevance. Subsequently, 110 reports were retrieved for further analysis and 35 selected based on the aforementioned selection criteria. These 35 articles were thoroughly reviewed and complications were recorded. Of these articles, nine discussed complications from the tubular, six from the endoscopic tubular assisted, eleven from the uniportal, and thirteen from the biportal approaches. Of note, two articles discussed both the uniportal and biportal techniques, and one discussed uniportal, biportal, and tubular. This process is illustrated in [Figure 1](#).

### 2. Microscopic Tubular Approach

Ross [10], in his retrospective cohort study, analyzed 302 consecutive cases for complications following the treatment of spondylotic diseases, epidural masses, or spinal cord stimulator implantations. These cases were complicated by one durotomy and two transient sensory deficits in the dermatomal distribution of the affected cervical nerve root. Additionally, of the 53 patients who underwent foraminotomy at the C5 level, three patients (5.7%) developed weakness at the corresponding nerve root level following the surgery. Two of these cases were transient, with patients regaining full function within three months, but one case was permanent. In another study of 45 patients treated for the surgical management of intradural-extramedullary spine tumors, 27 patients were treated with the tubular approach, resulting in three complications [11]. One patient developed a CSF leak, another wound dehiscence, and a third pneumonia (for a complication rate of 11.1%). Comparatively, of the 18 patients who underwent open surgical management in the same study, three patients developed a CSF leak and one a troponin elevation (for a complication rate of 22.2%).

Four additional studies, including one involving the surgical management of synovial cysts, two discussing tumors resections, and a fourth evaluating herniated discs were free of complications [12-15]. Balasubramanian et al. [16], studying a cohort of 25 patients undergoing tumor resection in the cervical or thoracic vertebrae, found two cases of post-surgical weakness. Additionally, Gandhi and German [17] reported one instance of wound dehiscence following resection of a meningioma, ventral to the C1 nerve roots. In a larger study of 118 patients who underwent either a microscopic tubular, uniportal, or biportal approach for the treatment of foraminal stenosis, the 50 patients in the tubular group experienced six complica-

tions including symptom recurrence (2), hematoma (2), dural tear (1), and a surgical revision (1) [18]. The studies discussing the microscopic tubular approach in the cervicothoracic spine are listed in Table 1.

### 3. Endoscopic Tubular-assisted

Of the six studies evaluating complications after using the endoscopic tubular-assisted approach, one study of 10 patients undergoing surgical decompression reported no complica-

tions [19]. In another paper, Baba et al. [20] described a set of 25 patients undergoing decompression due to ossification of the ligamentum flavum which resulted in thoracic myelopathy. Two complications resulted - one a dural tear which resolved without further treatment, and a second patient developed a postoperative hematoma which required emergent surgical evacuation.

In a larger study of 210 patients undergoing an anterior approach for decompression, one patient sustained an injury to their esophagus, one had C5 root paresis which resolved, two experienced transient dysphagia, two had incomplete decompression, and one had transient voice hoarseness [21]. In two additional studies, one consisting of 31 patients undergoing laminotomy and a second consisting of 38 patients undergoing either foraminotomy or discectomy, the former revealed one incident of C5 nerve root palsy and the latter a CSF leak requiring no intervention [22,23]. A randomized-control trial of 70 patients undergoing open anterior cervical discectomy or cervical micro endoscopic discectomy (33 in the open group, 37 endoscopic) revealed 48% of patients in the open group experienced subjective dysphagia or dysphonia, compared to 16% in the micro endoscopic group [24]. The authors attributed the substantial difference in laryngopharyngeal complications to several factors including the lesser distance the trachea and esophagus need to be retracted using the tubular approach and minimal soft-tissue dissection which subsequently reduces tissue edema. The papers studying the endoscopic tubular-assisted approach in the cervicothoracic spine are listed in Table 2.

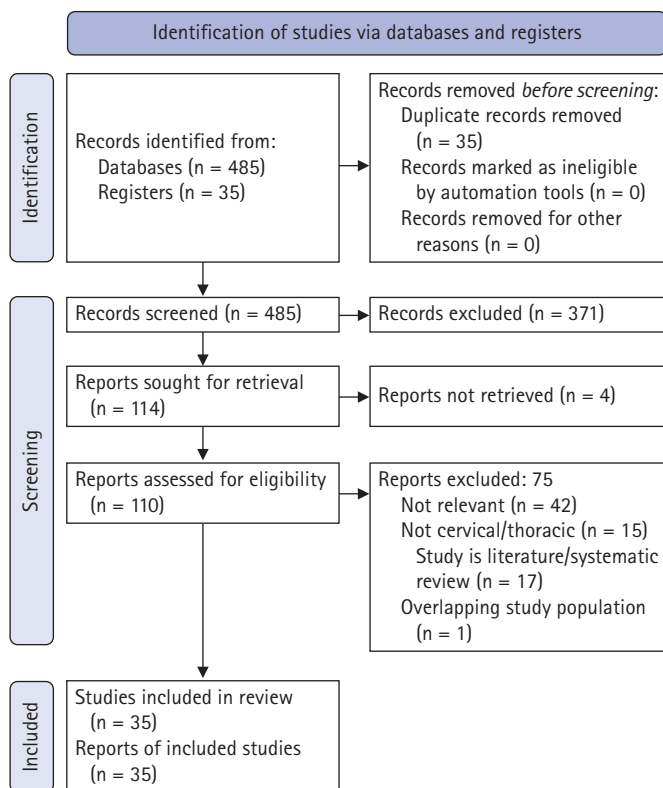


Figure 1. Flow chart of study inclusion.

### 4. Uniportal Endoscopic

Eleven studies were identified involving patients who underwent uniportal endoscopic spine surgery, with mention of post-surgical complications. Kim et al. [25], in a study of 254

Table 1. Studies of the microscopic-assisted tubular approach

First author	Study type	Number of patients	Complication(s)
Ross [10]	Cohort	302	Durotomy (n = 1, 0.33%), cervical root palsies/sensory deficits (n = 5, 1.7%)
Wong [11]	Cohort	27	CSF leak (n = 1, 3.7%), wound dehiscence (n = 1, 3.7%), HCAP (n = 1, 3.7%)
Soriano Sánchez [12]	Cohort	2	None
Balasubramanian [16]	Cohort	25	Lower extremity weakness (n = 2, 8%)
Salame [13]	Cohort	32	None
Gandhi [17]	Cohort	16	Wound dehiscence (n = 1, 6.3%)
Cho [15]	Case series	5	None
Dahlberg [14]	Cohort	54	None
Kim [18]	Cohort	50	Hematoma (n = 2, 4%), dural tear (n = 1, 2%), recurrence of stenosis (n = 2, 4%), revision (n = 1, 2%)

HCAP: healthcare associated pneumonia.

**Table 2.** Studies of the tubular-assisted endoscopic approach

First author	Study type	Number of patients	Complication(s)
Baba [20]	Case series	25	Dural tear (n = 1, 4%), hematoma (n = 1, 4%)
Parihar [21]	Cohort	210	Esophageal injury (n = 1, 0.48%), C5 root paresis (n = 1, 0.48%), transient dysphagia (n = 2, 1%), incomplete decompression (n = 2, 1%), transient voice hoarseness (n = 1, 0.48%)
Minamide [22]	Cohort	31	C5 root palsy (n = 1, 3.2%)
Lawton [23]	Cohort	38	CSF leak (n = 1, 2.6%)
Dahdaleh [19]	Cohort	10	None
Soliman [24]	Randomized controlled trial	37	Dysphagia (n = 5, 16%)

patients with degenerative spine conditions, reported complications in five patients including a C5 nerve root palsy, infection, drain tip retention, and two cases of inadequate decompression respectively. Lin et al. [26], in a retrospective analysis of 816 patients undergoing decompression or discectomy for thoracic or lumbar disorders, reported a complication rate of 2.57% with 15 patients sustaining inadequate decompression, one a dural injury, two permanent paresthesia, and three a seizure which the authors attributed to irrigation with cefazolin, an antibiotic with potential epileptogenic effects. In three other publications, for patients undergoing discectomy, cyst removal, or foraminotomy respectively, the authors reported complications including two CSF leaks in the first study, one dural leak and one case of transient hypesthesia in the second, and one case of transient hypesthesia in the third [27-29].

In a study of 55 patients undergoing decompression of the thoracic spine, complications including two epidural hematomas (one requiring surgical evacuation), two dural tears, two intercostal neuralgias, two deteriorations of the underlying myelopathy, and one case of leg dysesthesia were observed [30]. In another cohort of 84 patients undergoing either anterior or posterior full-endoscopic cervical discectomy, four surgery-related complications were noted [31]. In the anterior approach group, one patient experienced a transient postoperative headache and another an epidural hematoma requiring evacuation. In the posterior group, one patient had worsening neurologic function in the contralateral lower limb, but these symptoms resolved over three months; a second patient underwent a repeat surgery requiring an anterior approach.

Nie and Liu [32] and Li et al. [33], in patients undergoing spinal decompression reported one instance of post-operative headache (successfully treated with an epidural blood patch) and two dural tears as respective complications. In Kim et al.'s study [18] comparing the microscopic tubular, uniportal endoscopic, and biportal endoscopic approaches, the 38 patients in the uniportal group experienced two complications of a temporary nerve root palsy, and one recurrence of the foraminal

stenosis resulting in a complication rate of 7.8%. Finally, in a study where patients underwent either the uniportal or biportal approach for foraminotomy, the 32 patients in the uniportal group experienced three complications of incomplete decompression, durotomy, and transient C5 nerve root palsy [34]. The studies reporting on the uniportal endoscopic approach in the cervicothoracic spine are listed in Table 3.

## 5. Biportal Endoscopic

A total of thirteen studies examining the biportal endoscopic approach were identified. Of these, six were small studies where patients underwent either decompression or mass excision; these studies reported no complications [35-40]. A larger study of 228 patients reported one instance of a C5 nerve root palsy and another case of incomplete decompression as complications [25]. In a case series of seven patients undergoing foraminotomy for cervical radiculopathy, one patient sustained a dural tear [41].

In a cohort of 643 patients undergoing biportal endoscopic spine surgery for degenerative spinal disease by four experienced surgeons, 29 instances of a dural tear occurred, for an incidence of 4.5% [42]. In another study comparing the uniportal to the biportal approach for foraminotomy, of the 33 patients in the biportal group, one patient's decompression was incomplete, and there was one instance of each a durotomy, epidural hematoma which did not require operative management, and persistent dysesthesia [34].

Deng et al.'s case control study [43] of 14 patients undergoing decompression for ossification of the ligamentum flavum showed two cases of hyperalgesia, two cases of head and neck pain, and one instance of CSF leakage as complications. In a retrospective review of 109 patients undergoing the biportal technique for the treatment of symptomatic cervical disc herniations, there were no major complications, but one instance of motor weakness of shoulder abduction and elbow flexion secondary to fluid retention in the dorsal epidural space of the



**Table 3.** Studies of the uniportal endoscopic approach

First author	Study type	Number of patients	Complications
Kim [25]	Cohort	254	C5 root palsy (n = 1, 0.39%), drain tip retention requiring extraction surgery (n = 1, 0.39%), infection (n = 1, 0.39%), inadequate decompression (n = 2, 0.79%)
Lin [26]	Cohort	816	Inadequate decompression (n = 15, 1.84%), dural injury (n = 1, 0.12%), permanent paresthesia (n = 2, 0.25%), seizure (n = 3, 0.37%)
Xiaobing [27]	Case series	14	CSF leak (n = 2, 14.3%)
Ruetten [30]	Cohort	55	Epidural hematoma (n = 2, 3.6%), dural tear (n = 2, 3.6%), intercostal neuralgias (n = 2, 3.6%), leg dysesthesia (n = 1, 1.8%), deterioration of myelopathy (n = 2, 3.6%)
Ruetten [28]	Cohort	7	Dura leak (n = 1, 14.3%), hypoesthesia (n = 1, 14.3%)
Ye [29]	Case series	9	Transient hypesthesia (n = 1, 11.1%)
Yang [31]	Cohort study	84	Post-operative headache (n = 1, 1.2%), hematoma (n = 1, 1.2%), transient worsening of neurologic function in the contralateral limb (n = 1, 1.2%), repeat disc herniation (n = 1, 1.2%)
Nie [32]	Cohort	13	Post-operative spinal headache (n = 1, 7.7%)
Li [33]	Cohort	30	Dural tear (n = 2, 6.7%)
Kim [18]	Cohort	38	Transient nerve root palsy (n = 2, 5.3%), recurrence of stenosis (n = 1, 2.6%)
Kang [34]	Cohort	32	Incomplete decompression (n = 1, 3.1%), durotomy (n = 1, 3.1%), transient C5 nerve root palsy (n = 1, 3.1%)

**Table 4.** Studies of the biportal endoscopic approach

Author	Study type	Number of patients	Complications
Kim [25]	Cohort	228	C5 root palsy (n = 1, 0.44%), incomplete decompression (n = 1, 0.44%)
Kim [35]	Case report	1	None
Song [41]	Case series	7	Dural tear (n = 1, 14.3%)
Park [42]	Cohort	643	Dural tear (n = 29, 4.5%), meningocele (n = 1, 0.16%)
Zhu [36]	Case series	1	None
Kim [37]	Case series	1	None
Kang [34]	Cohort	33	Incomplete decompression (n = 1, 3.0%), durotomy (n = 1, 3.0%), hematoma (n = 1, 3.0%), persistent dysesthesia (n = 1, 3.0%)
Deng [43]	Cohort	14	CSF leak (n = 1, 7.1%), head and neck pain (n = 2, 14.3%), hyperalgesia of lower extremities (n = 2, 14.3%)
Jung [44]	Cohort	109	Motor weakness of shoulder abduction and elbow flexion (n = 1, 0.92%)
Wang [38]	Case series	5	None
Zhu [39]	Case series	6	None
Kang [40]	Case series	3	None
Kim [18]	Cohort	30	Recurrence (n = 2, 6.7%), dural tear (n = 1, 3.3%), transient nerve root palsy (n = 1, 3.3%)

patient's cervical spine which resolved spontaneously over the ensuing month [44]. Finally, in Kim et al.'s study [18] of patients undergoing either the microscopic, uniportal, or biportal approaches for treatment of foraminal stenosis, of the 30 patients in the biportal group, there were two instances of recurrence, one dural tear, and one transient nerve root palsy for a complication rate of 13.3%. The manuscripts that involve the biportal endoscopic approach in the cervicothoracic spine are listed in Table 4.

## DISCUSSION

### 1. Interpretation and Implications

The present review provides a comprehensive list of com-

monly encountered complications while performing minimally invasive surgery on the cervical or thoracic spine for the treatment of degenerative diseases, neoplasms and cysts. This analysis provides a list of complications surgeons should consider when considering a given minimally-invasive approach for the treatment of a certain spinal pathology in a specific anatomical area. Overall, our review suggests that MIS approaches have less severe complications than open approaches.

Nevertheless, similar complications did occur in all four of the minimally invasive groups. These included dural tears, hematomas, nerve root palsies, and incomplete decompressions or recurrences of the underlying stenosis. Due to the recent and rapid adoption of minimally invasive approaches to the cervical and thoracic spine, associated with continued improvement in equipment design, these procedures involve a substantial

learning curve. It is possible that as time evolves, the incidence of these complications will decrease as surgeons become more experienced in the use of these techniques.

## 2. Limitations

The present review has several limitations. Firstly, a small number of the selected studies contained patients who underwent either cervical, thoracic, or lumbar surgery and did not distinguish between these patient groups when reporting complications. Additionally, one study examining patients undergoing MIS spine surgery included a very small number of open cases in their cohort, introducing the possibility that a small number of the reported complications could have been from open surgery [25]. Some complications, including post-operative headache, were subjective leading to the potential of interviewer bias. Moreover, seeing that many of the included studies were retrospective analyses and not randomized-control trials, the risk of sampling bias and the involuntary exclusion of other complications must be considered.

When considering some of the rates of complications such as dural tear which in one study was reported to be 4.5%, the experience of the surgeon with the technique must be considered; this is especially true for some of the more novel techniques such as the biportal approach. Our review is unable to capture where along the learning curve of various MIS techniques the surgeons were, which may heavily influence complication rates. Finally, many of the contained studies did not provide detailed patient demographic and clinical characteristics which could influence the rate of various complications.

## NOTES

### Ethical statements

Not applicable.

### Conflict of interest

No potential conflict of interest relevant to this article.

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# Prodrome to Seizure in Transforaminal Endoscopic Surgery: A Series of 9 Cases

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**Objective:** Percutaneous transforaminal endoscopic lumbar discectomy (PTELD) is safe and effective. Perioperative or postoperative seizures are a rare complication that can be prevented by promptly identifying prodromal symptoms and signs. This study aimed to identify prodromal symptoms and risk factors of avoidable seizures in patients undergoing PTELD and to quantify irrigation fluid ingress into the epidural space on immediate postoperative magnetic resonance imaging (MRI).

**Methods:** This retrospective analysis included patients who underwent PTELD under local anesthesia from February 2018 to June 2022. Surgical records were reviewed to identify patients who developed prodromal symptoms, and immediate postoperative MRI was evaluated for radiological correlations.

**Results:** Nine patients developed prodromal symptoms of neck pain (n=6), upper dorsal pain (n=7), headache (n=2), confusion (n=2), visual disturbance (n=1) and hemodynamic alterations (n=4). No patients had seizures. Calcified lumbar disc herniation-associated posterior apophyseal ring fracture, central lumbar disc herniation, obesity, double-level surgery, use of an automated pump, and a large working channel endoscope were associated with an increased fluid flow rate for epidural work and duration of surgery. MRI showed significant epidural fluid collection cranial to the operative level, reaching the thoracolumbar junction, in patients with prodrome, suggesting increased intracranial pressure due to thecal sac compression.

**Conclusion:** Prodromal symptoms should be considered a red flag for avoidable seizures. The duration of surgery and infusion fluid flow rate are controllable risk factors during surgery. Risk factors should be kept in mind. The judicious use of automated pumps and larger channel working endoscopes is recommended.

**Key Words:** Transforaminal, Endoscopy, Spine, Prodrome, Seizures, Intracranial pressure

## INTRODUCTION

Percutaneous transforaminal endoscopic lumbar decompression (PTELD) is a minimally invasive technique for treat-

ment of lumbar disc herniation (LDH) for discectomy and lumbar canal stenosis (LCS) decompression [1]. PTELD, PIELD (percutaneous interlaminar endoscopic lumbar decompression) are all full endoscopic spine surgeries (FESS) techniques

and exponentially growing. The clinical results of FESS were identified as being equal to those of the microsurgical technique, adding great advantages as reduced post-operative pain, rapid rehabilitation, reduced anatomic trauma, low post-operative cost of care, facilitation of revision surgery [2,3]. PTELD is safe and effective, though with low rate of complications, such as neural and vascular structure injuries, dysesthesia, visceral injury, dural tears, infection, inadequate decompression of neural tissue and re-herniation [4]. Seizure in peri-operative and post-operative period of PTELD is an unexpected complication reported in previous literature [5-11]. In a study by Choi et al. [5] specific surgical factors like increased irrigation pressure and duration of surgery has been postulated as causative factors. The prodromal symptoms and sign for seizure episode in FESS are neck and upper dorsal pain, visual disturbances, headache, confusion and intra-operative hemodynamic alterations [5,9,12]. We primarily reinforce the hypothesis that the epidural fluid ingress cranio-caudal to operative level can give prodrome to seizures during PTELD surgery by raising the extra-thecal pressure (ETP/ epidural pressure), intra-thecal pressure (ITP) and furthering to raised intracranial pressure (ICP) which may lead to full blown seizures. Secondly, we identified and objectified factors in our cases which led to increase in irrigation pressure and duration of surgery. A literature search was done to find out the additional factors responsible to these fluid dynamics. Finally, the preventive methods are suggested.

## MATERIALS AND METHODS

This is a retrospective analysis of all the patients who developed prodromal symptoms while undergoing PTELD under local anesthesia (LA) for LDH/LCS at our center from February 2018 to June 2022 (51 months). All the procedures were carried out by a single surgeon at our institute.

Prodromal symptoms were defined as occurrence of broad spectrum of pre-ictal symptoms that may be experienced during PTELD procedure. The symptoms can be neck pain, upper dorsal pain, headache, confusion, temporary visual disturbance, profuse sweating, confusion and or hemodynamic disturbance. A sudden rise or fall in mean arterial pressure (MAP) >20 mmHg, sudden alteration in pulse rate (PR) >20 from preceding baseline were considered a significant hemodynamic alteration.

The demographic features were analyzed from medical, surgical, and imaging records to find out a plausible explanation. Age, sex, any pre-existing aggravating condition for instigating episode of seizure if any, Body mass index (BMI), level of sur-

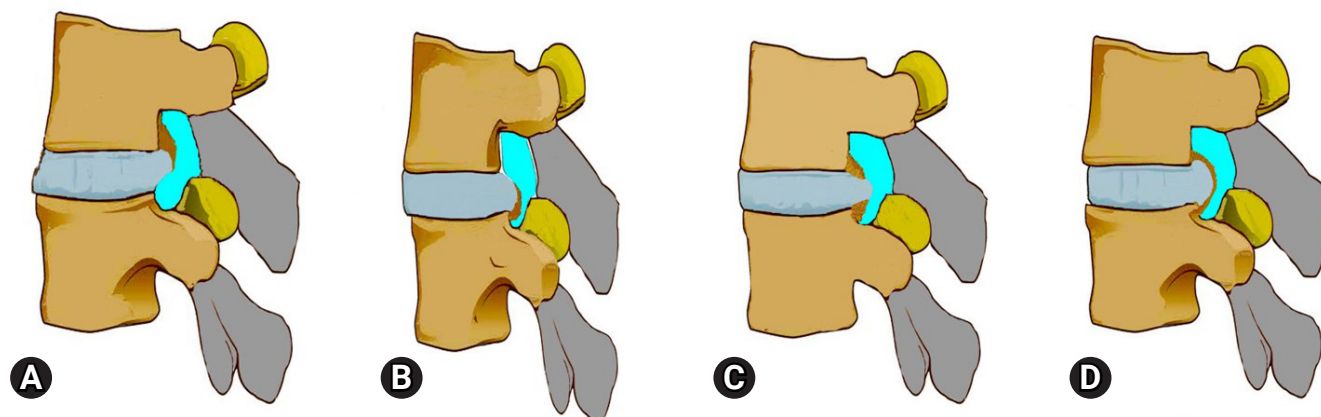
gery, number of surgical levels, grade of lumbar disc herniation as per MSU classification [13], type of offending pathology and associated conditions projecting into the spinal canal. The definitions were: posterior apophyseal ring fracture (PARF); separation of the bony fragments at the posterior rim of the lumbar vertebral endplate (superior or inferior). Calcified lumbar disc herniation (CaLDH); calcification or hardening of the annulus in herniated part of LDH or associated with calcified end plate spurs (Figure 1). LDH is nucleus pulposus herniation with or without end plate cartilage dislocation and annular avulsion/tear. LCS is ventral or lateral recess stenosis [14].

An independent anesthesiologist was present during the surgical procedure. The surgery was done in LA and conscious sedation in prone position. Intramuscular midazolam (0.05 mg/kg) and diclofenac were given within one hour of surgery. Half a dose of titrated infusion of dexmedetomidine (0.5-1 µg/kg) was given slowly with an intravenous dose of 1 µg/kg of fentanyl bolus ten minutes before the surgery. Additional doses as needed were given.

A transforaminal approach through Kambin's triangle was used. Fluoroscopy was used for guidance of entry point. The site of annular puncture is medial pedicular line in AP view and posterior vertebral line in lateral view. The skin entry point is around 9-14 cm from the midline and at angle of 20°-30° from frontal plane of body depending on level of surgery performed. The intended entry tract is infiltrated with 1% lidocaine plus bupivacaine in 1:1 ratio. A 16-inch 18-gauge needle is inserted to site of annular puncture in Kambin's triangle with continuous patient's feedback. Trajectory can be changed by bevel of the needle, and cranio-caudal or dorso-ventral lift of the stylet hub of needle before steering it further. Site of annulus puncture is further infiltrated with 1.5-6 mL of local anesthetic mixture. Constant communication with the patient eases out anxiety.

Through a 7 mm incision, threading of tapered dilating trocar is done over a guidewire. The beveled working cannula was railroaded, and endoscope was introduced (Maxmore system-Germany/Richard wolf system-Germany). The removal of the offending compression was done with straight and articulated instruments to cut, tease, grab, deliver the culprit fragment. LDH excision was done along with optimum compressive ventral stenosis removal. The techniques employed depended upon the pathology and were standard basic techniques of outside in (OI) or inside out (IO) or FEE (flat epidural entry), with modifications as needed for the cases at author's institute.

Inside out (IO) was the workhorse approach: An approach at



**Figure 1.** Illustration of the calcified disc component of ventral stenosis as noted with respect to PTELD. (A) Only an upper vertebral end plate spur contributing to stenosis with lumbar disc herniation (LDH). (B) Only a lower vertebral end plate spur contributing to stenosis with LDH. (C) Both end plate spurs contributing to stenosis with LDH. (D) Only annulus hardening or partial calcification with LDH.

a 15° to 20° angle was taken. The disc was pierced, and the subannular disc was removed before cutting the annular anchorage and working in epidural space.

Under endoscopic vision a burr was used to perform a foraminoplasty when there was a technical requirement to reach more dorsal. Endoscopic drill system (Nouvag system, USA) was used during the procedure. Offending or compressive structure is removed completely. End points of decompression were as many possible of the suggested endpoints of decompression in author's previous article either direct or indirect were targeted [15]. The direct signs of end point of decompression were magnetic resonance imaging (MRI) matched retrieval of fragment, fresh gush of epidural bleed, neural fall back and complete visualization of roots, dural sac, strong dural pulsation, dural flutter on cough impulse. The indirect signs of end point were subsidence of pain, intra-operative negative straight leg raise test, annular flap mobility, smooth sweeping of discal floor etc.

Skin incision was closed, and all patients are mobilized as per their tolerance and limb power. Patients were then advised to undertake passive/active physiotherapy.

The technical difficulty faced during the PTELD due to targeted disease pathology or patient factor, or any special technical accessory/modification used in the case were noted. When prodrome occurred then, the PTELD was halted, irrigation fluid was stopped, ventilation with O<sub>2</sub> mask given, vital monitoring done, patient counselled and stabilized to comfort. After the prodrome has passed, the procedure was again continued till completion.

The duration of surgery (minutes) was noted from position-

ing of patient to end point of decompression, duration of irrigation of fluid (minute), irrigation flow method (gravitational/automated pump), frequency of usage of intermittent manual pulsed pressure (IMP) and the ingressed fluid volume in mL were noted. Gravity method used at our institute. It constituted of non-latex irrigation tubing connected to 3 L of normal saline suspended at a height of 1.5 m from the height of table to maintained probably a pressure of 74–110 mm H<sub>2</sub>O (Figure 2A, B). IMP was used whenever higher pressure was needed for hemostasis for clear vision. The valved hand pump inflator connected to 3 L of saline bottle was used to give IMP. This was done with an ETO sterilized custom-made valved inflation bulb (Figure 2C) which was introduced into the saline bottle and manually inflated alike a manual sphygmomanometer bulb. Each pulse by experience arbitrarily had been fixed at five manual compressions of inflation bulb, which suffices to take care of a FESS epidural bleed. In a usual surgery it's been noted that for PTELD in a simple LDH, less than 5 pulse (5 compression×5 times) are needed. The need for pulses in our experience of 14 years of performing PTELD, increases with complexity of procedure, need for epidural work, bony stenosis, and duration of surgery. The number of IMP pulse that was used were objectively categorized as less than less than <5, 6–10, 11–15, 16–20, and >20.

As a protocol, at our institute immediate post-operative MRI T2 sagittal and axial sequences at the operated levels are done within two hours in all patients for documentation and for conformity of decompression in all cases of PTELD. Additionally, in all the patient who had prodromal symptoms underwent the MRI up to section of lower dorsal spine.



**Figure 2.** (A) Hydrodynamic irrigation pressure setup. (B) A TURP double-lumen tube, one working at a time connected to two 3-L saline bottles hanging by a drip stand around 1.5 m from the table height. (C) Sterile plunger tubing with a manual pressure pump (a valved bulb). The trocar of the plunger is plunged into the air column part of inverted saline bottles, and intermittent manual pressure pulses by the bulb (yellow asterisk\*) are given when any obscurity of endoscopic visualization due to bleeding occurs.

MRI was reported by a spine radiologist with more than 10 years of experience in only spinal disorders reporting. The reporting was categorized as adequate/inadequate decompression and presence of post-operative atypical findings. Atypical finding was the presence of fluid in epidural space more than two segment level. The presence of fluid ingress in epidural space was further jotted as cranio-caudal to index operative level. The number of segments above and below encroached by fluid was noted. Furthermore, it was documented whether it was anterior or posterior or circumferential. Myeloblock or any compression on dural sac other than index surgical compression was also noted above the operated level.

The follow up period, evaluation of functional outcomes was done using VAS score in leg and back, the patient satisfaction index [16], Macnab outcome score were noted with any other complications.

## RESULTS

During the study time period of 51 months, 290 patients were operated for PTELD and 9 patients developed prodromal symptoms. No patient developed post-prodromal seizure sequelae. Detailed description of patient demographics who developed prodromal symptom during PTELD is tabulated in Table 1.

There were 3 male and 6 female patients (average age  $36.1 \pm 12.85$  [21–58] years). Four patients were obese and 4 patients were overweight as per BMI. The most common level of LDH in our study was L4–5 (n=8). One patient had double level surgery at L2–3 and L4–5. As per MSU classification: 2AB (n=5), 3AB (n=2), 2A (n=2) and 1AB (n=1) out of total 10 LDH levels.

Four patients had complete myelographic block. Five patients had calcification (CaLDH), which was annulus calcification in 1 and endplate spurs in 4 patients. PARF was the pathology in 2 patients.

Surgery was done using the basic techniques of IO in all cases under LA. In patients with CaLDH, the IO technique needed additional technique modifications of calcified ventral decompression for removal of the hardened tissue. Additionally, burred foraminotomy was needed in one patient for approaching dorsal canal, medialization and improving the reach in epidural space.

The prodromal symptoms started at  $60.89 \pm 22.59$  (26–98) minutes from onset of irrigation of saline, towards the end stage of surgery in majority (n=7) of patients. All the 9 patients had started to complain of non-painful discomfort omit at start of prodromal symptoms. Five patients had hemodynamic disturbance in which 4 patients had sudden shoot up in blood pressure and tachycardia and one developed bradycardia (Table 2). Procedure was halted till prodrome passed by and 3 patients were given prophylactic intravenous levetiracetam. Remaining procedure could be executed afterwards. In two patients, procedure had to be halted twice due to prodromal symptoms.

The total fluid volume of saline infused was  $7.96 \pm 2.53$  (5.2–16.2) L. Multiple IMP was needed during surgery to maintain unobscured vision in all the patients. Epidural fat pop out hindered the endoscopic vision in 5 cases all were obese. These patients required more IMP to keep the endoscopic vision.

Technical novice of automatic pump was experimented before a proposed buyout for the first time by author in one patient. The irrigation fluid flow rate was started and maintained at 150 mL/min. Endoscope of a larger diameter of 4.3 mm was



**Table 1.** Detailed description of the demographics, radiological findings, and surgical records of patients in whom prodromal symptoms developed during PTLED

Patients No.	Age (yr)	Sex	BMI (kg/m <sup>2</sup> )	Disc pathological morphology				Surgical parameters of inside out PTLED					MRI fluid spinal signs			Hypothesis			
				Level	Myeloblock complete	Disc typing location	MSU classification	Associated pathology: ventral stenosis, calcified annulus, end plate spur	Duration of surgery (min)	Duration of irrigation fluid (min)	Symptom started from onset of irrigation (min)	Fluid infusion volume (mL)	Manual pulse pressure frequency	Any new technology/ device deviation in execution other than the routine	MRI fluid spinal segment region/levels evidence cranial to decompression		MRI fluid spinal segment level evidence below decompression	Anterior (A)/posterior (P) or both (B)	MRM (irregular fluid egress in soft tissue plane)
1	24	F	32	L2-3, L4-5	-	PC	L2-3: 1AB, L4-5: 2AB	-	122	93	67	8,500	23	-	(D12-L1): 4	2	B	-	- Fat popping out
2	21	M	22	L4-5	+	C	2AB	Calcified end plate spur	92	66	53	5,500	17	-	(D12-L1): 4	2	A	+	- Proximal and double level surgery - Calcific disc removal
3	58	F	37.84	L3-4	-	PC	2AB	-	138	107	33, 95	16,200	19	Automated fluid pump	(D12-D11): 5	3	B	+	- Fat popping out - Bleeding - Automated pump - Surgery stopped twice - Calcific disc removal
4	42	F	27.24	L4-5	-	PC	2AB	Hard annulus	125	93	84	11,400	24	Working channel 4.3 mm	(D11-D12): 5	2	B	+	- Large working channel endoscope needing more fluid to maintain a clear field - Calcific disc removal
5	47	M	25.61	L4-5	-	C	2A	Calcified end plate spur, PARF	146	104	98	10,400	17	-	(D11-D12): 5	1	B	+	- Removal of PARF (more epidural work) - Fat popping out
6	36	F	29.59	L4-5	+	C	2A	Calcified end plate spur	110	80	56	5,200	14	-	(L2-3): 2	1	B	+	- Calcific disc removal - Fat popping out
7	22	M	33.2	L4-5	+	C	3AB	Calcified end plate spur	112	87	68	5,500	19	-	(L1-2): 3	1	B	-	- Calcific disc removal - Fat popping out
8	30	F	27.55	L4-5	-	PC	2AB	-	106	78	26, 59	9,100	18	-	(D12-L1): 4	1	B	-	- Calcific disc removal - Epidural bleeding - Surgery stopped twice
9	45	F	34.6	L4-5	+	C	3AB	PARF	105	81	63	8,100	19	-	L1-L2: 3	1	B	-	- Fat popping out - Epidural bleeding - Removal of PARF (more epidural work)

PTLED: percutaneous transforaminal endoscopic lumbar discectomy, M: male, F: female, BMI: body mass index, BP: blood pressure, C: central, PC: paracentral, PARF: proximal apophyseal ring fracture, MRM: magnetic resonance myelogram, A: anterior, P: posterior, B: both.

**Table 2.** Details of prodrome symptoms during PTELD

Patients No	Local pain/ neurological pain	Headache	Neck pain	Upper back pain	Confusion	Visual disturbance	Discomfort	Sweating	Hemodynamic alterations (> 20 mmHg rise in blood pressure [↑ BP] or bradycardia [BC]/tachycardia [TC])
1	-	+	-	+	+	+	+	+	↑ BP/TC
2	-	-	+	+	-	-	+	-	↑ BP/TC
3	-	-	+	+	+	-	+	+	-
4	-	+	-	-	-	-	+	-	-
5	-	-	+	-	-	-	+	-	↑ BP/TC
6	-	-	+	+	-	-	+	-	BC
7	-	-	-	+	-	-	+	-	↑ BP/TC
8	-	-	+	+	-	-	+	-	BC
9	-	-	+	+	-	-	+	-	↑ BP/TC

PTELD, percutaneous transforaminal endoscopic lumbar discectomy TC: tachycardia, BC: bradycardia.

used in another one case instead of routine 3.7 mm used by author otherwise always for another proposed buyout at the institute.

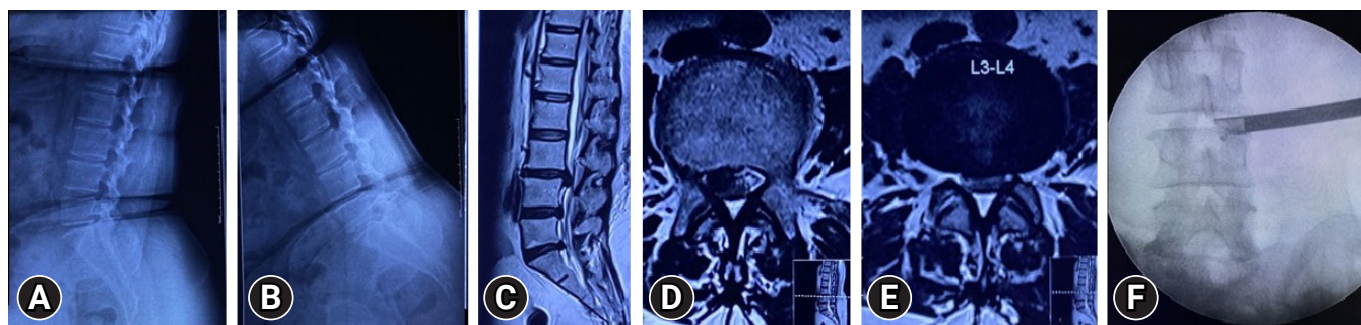
Post-operatively, adequate decompression was confirmed on MRI for index pathology in all patients with improved immediate patient outcome measures. Irrigation fluid collection in epidural space in cases with prodromal symptom was an average of 3.8 segment above and 1.5 level below the operated level causing thecal sac compression. The fluid collected circumferentially (both anterior and posterior epidural space) in 8 cases and anterior epidural space only in 1 case. The irrigation fluid extravasated extra canalicular into adjacent soft tissue in irregular pattern, which was visible in magnetic resonance (MR) myelogram in 5 cases. MR myelogram showed variable segment myeloblock was present in all patients post-operatively without any symptoms (Figure 3, 4).

The follow up period was ranging from 3–25 (9.65±9.32) months. The evaluation of functional outcomes were done using VAS score in leg and back. The VAS score of leg improved from 8.2±1.3 pre-operatively to 0.44±0.52 at final follow up. The VAS score of back improved from 3±1.18 pre-operatively to 1.11±0.33 at final follow up. The patient satisfaction index was 1 in all patients. The clinical success of procedure measured Macnab outcome as excellent in 7 patient and good in 2 patients. No other complications were noted.

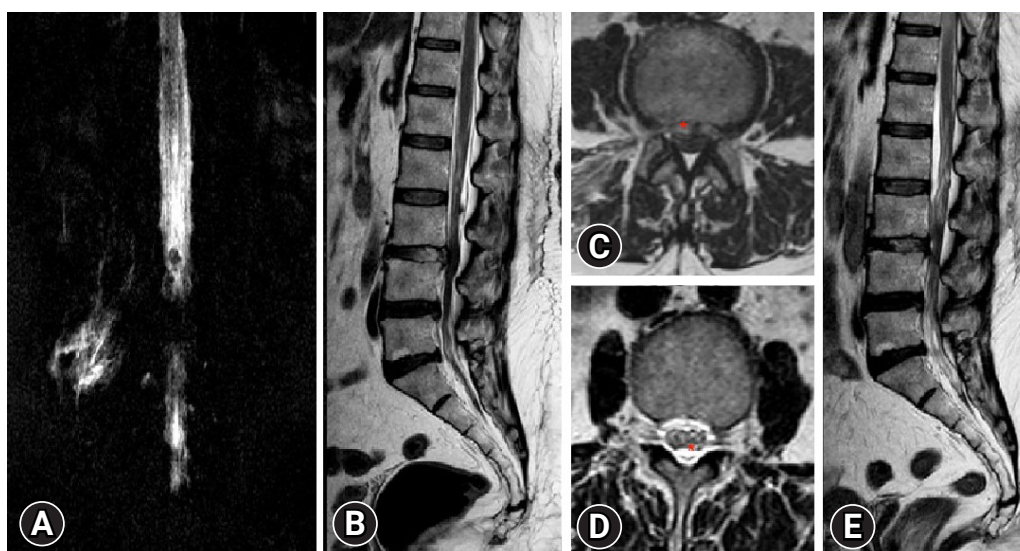
## DISCUSSION

The prodrome of an already manifested seizure has been described in general medical literature [5,9,17]. These prodromes are neck pain, back pain headache, visual disturbances, dizziness, and constriction feeling in saddle area and chest pain [5,9,12]. Identification of prodromes could be a red flag sign should be the focus especially if done under LA, as carrying out the PTELD under general anesthesia (GA) can mask the early symptoms of elevated ICP leading to serious and devastating complication. LA also allows communication between the patient and surgeon which could alert regarding the impending seizures [5]. Its logical to infer that when FESS is done under GA, chances of manifestation become less as patient is on medications which have suppressive effect and increase the threshold of seizures.

Although the definite cause of seizure in PTELD/PIELD surgeries remains uncertain, many postulates have been made in literature relating to patient characteristics, intra-operative and surgical factors. There are many causal possibilities of seizures in FESS (PTELD) specifically or in general and are tabulated



**Figure 3.** Case No. 3. A 58-year-old woman in whom conservative treatment had failed, with a 9-month history of unilateral right radiculopathy with disability. (A, B) No instability on dynamic radiographs. (C–E) T2-weighted sagittal and axial magnetic resonance imaging sections showing L3–4 right MSU classification 2AB discs. More fat than usual is present in the epidural space. (F) The "inside out" approach used in surgery, with transforaminal endoscopic discectomy decompression. The image shows the perioperative position. Perioperatively, the fat popping out obstructed the endoscopic visualization, requiring more time and fluid for decompression.



**Figure 4.** Case No. 3. Immediate 2-hour postoperative magnetic resonance imaging (MRI) showing: (A) A magnetic resonance myelogram showing extra spinal fluid and myeloblock. (B) T2-weighted mid-sagittal MRI showing adequate decompression, but a fluid intensity strip around the dura in the ventral, dorsal, and cranio-caudal space. Also noted is a small air bubble in the dorsal epidural space at upper end of L3. (C) Proximal to the L3 mid-vertebral body, an axial T2-weighted image shows the clumping of roots, and fluid (red asterisk\*) with the median posterior longitudinal ligament. (D) Proximal to the L1 mid-vertebral body, an axial T2-weighted image shows the clumping of roots. Dorsal to the dura, it is appreciable that the fluid (red asterisk\*) is ventral to the posterior epidural fat. (E) At 6 weeks of follow-up, T2-weighted sagittal MRI shows the disappearance of fluid (as compared to Figure 5B), the reappearance of fat ventrally in the upper epidural space (as compared to Figure 4C), and consolidating annular healing without compression.

(Table 3) [8,11,17–23].

Increasing dose of sevoflurane is known to increase the epileptiform changes in electroencephalogram (EEG) and it is advised to keep a minimum alveolar concentration below 1.5 to reduce chances of any seizure activity. Rapid decline in sevoflurane concentration, sudden CNS excitation, and hypercarbia while extubating and re-emergence from anesthesia, can be a potential risk factors for seizure [19,24].

Generalized tonic clonic (GTC) seizure in PTELD for LDH in GA has been reported due to probable causative factor of pneumocephalus due to dural tear, prolonged saline irrigation and sevoflurane/nitrous oxide ( $N_2O$ ) anesthesia. Low blood gas partition coefficient of  $N_2O$  contribute in raising ICP by expanding the volume of the pneumocephalus [11]. Inadvertent administration of the non-ionic contrast media (iohexol) into the thecal sac in PTELD has been reported [11]. Cephalosporin

**Table 3.** Conditions that can instigate seizure episode

Non procedure related seizure [17]	FESS procedure related	
	Non-surgical	Pathological/surgical/technical causes
Hypoxia	Propofol [18]	Intrathecal dye insertion [8]
Previous history of epilepsy	Sevoflurane [19]	Dural tear
Cerebrovascular accident (CVA) (ischemic/hemorrhagic)	Emergence from general anesthesia [20]	Pneumocephalus [11]
Previous brain tumor/traumatic brain injury/meningitis/encephalitis	Opioids (morphine, tramadol) [21]	Advanced indications of PTELD that increase time/pressure of irrigation:
Electrolyte imbalance (hyponatremia, hypocalcemia)	Antibiotic (cefazolin, beta lactam antibiotics) [22]	- Calcified disc <sup>a</sup>
Hypoglycemia	Lignocaine sensitivity [23]	- Central disc <sup>a</sup>
Fatigue and stress		- Posterior apophyseal ring fracture <sup>a</sup>
		Obesity <sup>a</sup>
		Epidural lipomatosis <sup>a</sup>
		Multilevel FESS <sup>a</sup>
		Diameter of working channel of endoscope <sup>a</sup>
		Automated pump <sup>a</sup>

FESS: fully endoscopic spine surgery, PTELD: percutaneous transforaminal endoscopic lumbar discectomy.

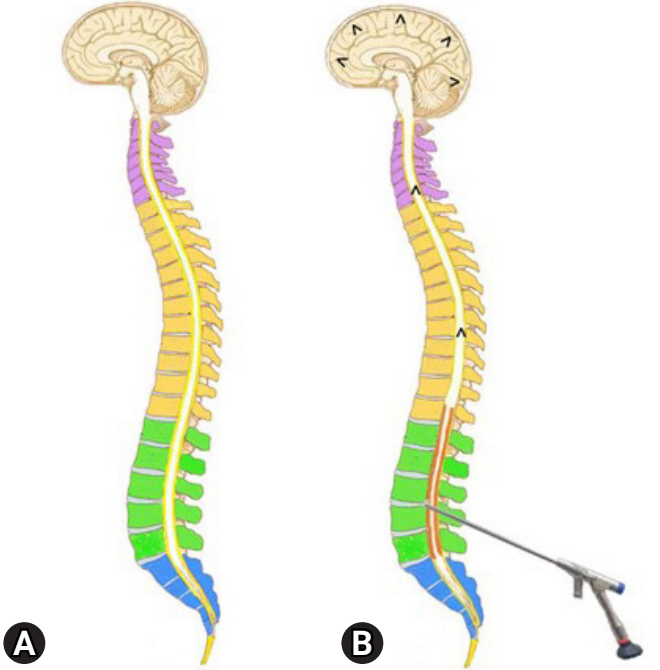
<sup>a</sup>Proposed risk factors in the current series.

has also been reported as potential epileptogenic because of the antagonism of the GABA receptor, durotomy or allergy [10].

The epidural space is a potential intra-canalicular space that extends throughout the spine. Continuous irrigation with normal saline is required in PTELD to maintain a clear endoscopic visual field for proper surgical execution. The hypotheses by Choi et al. [5] was that the ETP due to continuous infusion of saline into the epidural space could compress the thecal sac in cephalad direction. This could increase the ITP and that in turn raises ICP (Figure 5). The maximal cervical epidural pressure in those with neck pain has been significantly higher than those without neck pain suggesting, epidural pressure can affect the ICP [5,12]. It was also related to the time of surgery. It's been seconded in multiple other studies. [7,10,25,26]. So, continuous fluid infusion rate/pressure and duration of surgery are the two postulates of increase ETP in a PTELD.

Higuchi et al. [27] objectified on MRI and found that the thecal compression was volume dependent. In literature, people with no intracranial pathology, epidural pressure (EP) and intracranial pressure (ICP) has been shown to exhibit a linear co-relation [25,27,28]. In this study, we noted presence of fluid collection around thecal sac on T2W sagittal and axial section of immediate post-operative MRI in patients who developed prodromes (Figure 6). The possibility that increased ICP occurred was strongly considered.

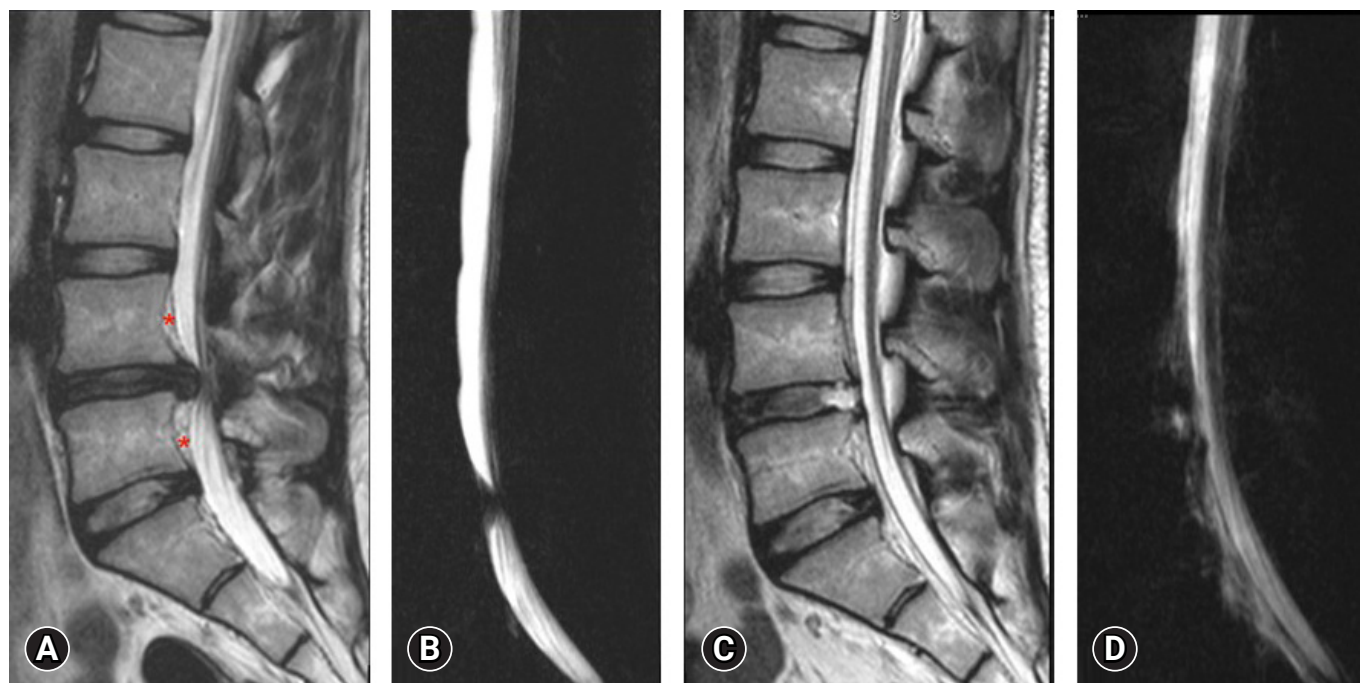
The natural and physical pathway by which fluid egress/out-flow regulates the ETP in FESS The fluid egress is through separate channel or working channel of the uniportal endoscope in FESS. Leakage of fluid along dural sleeves of spinal nerves and



**Figure 5.** (A) Illustration showing the epidural space as a potential space that extends throughout the spine and brain. (B) The increased epidural pressure due to a long-duration saline infusion would compress the thecal sac and expand the potential space with irrigation saline (red), squeezing out the cerebrospinal fluid cranially and precipitating seizure.

foraminal spaces also occurs and is related to the size of the intervertebral foramen, the density of the fatty tissues around it, any adhesions, and foraminal stenosis [29]. Lymphatic drainage in epidural space is another possibility [30]. Additionally,





**Figure 6.** Case No. 2. (A) T2-weighted sagittal magnetic resonance imaging (MRI) showing central disc herniation. Chronicity is evident by the fat deposits (red asterisk\*), posterior to the vertebral body of L4 and L5 and ventral to the posterior longitudinal ligament. It is elevated by both end plate spurs. (B) Lateral magnetic resonance myelogram showing complete myeloblock. (C) Postoperative T2-weighted sagittal MRI showing complete decompression. A thin strip of fluid three segments above and below, ventrally only. (D) Postoperative lateral magnetic resonance myelogram showing extra spinal fluid and an indenting anterior compressive fluid strip making the margins indistinct and wavy.

the rise in ICP will be dependent on intra-cranial compliance of the patient and by the amount of intra-cranially absorbed CSF [27,28].

The spectrum of indications for PTELD are directly related to the surgeon's experience [14,31]. The surgical duration increase occurs with complex pathological subtypes dealt with PTELD like CaLDH, CLDH, obesity, multiple level surgery, upper lumbar PTELD and PRAF. CaLDH was considered an absolute contraindication in a demi decade old literature. This was due to difficulty and increased failures [31].

Lumbar posterior apophyseal ring fracture (PARF) is characterized by the separation of the bony fragments at the posterior rim of the lumbar vertebral endplate. Conventionally open surgery has been a standard method of care for PARF over the past 3 decades. Successful removal of PARF using FESS has been described and is still in nascent stages [32]. In a study by Yuan et al. [33] the mean operation time in the LDH with PARF was significantly more than LDH without PARF using PTELD (105.4 min vs 83.9 min) ( $p=0.001$ ) and surgical complications of dural tears (6.3%) were more common in the PARF group ( $p=0.025$ ). PARF being a more technically demanding indication, required more of epidural work during surgery.

Calcified disc herniation (CaLDH) is a subtype LDH with calcification of herniated fragments [14]. The chronicity of herniation leads to calcification of annulus, or the end plate spurs contributing to ventral stenosis (Figure 1). PTELD gives an advantage of direct access to ventral pathology, minimal retraction of root, a more in-plane dissection, avoiding retraction of neural tissue as against in posterior approach. A CaLDH is still difficult to treat using PTELD due to severe adhesions and more epidural work needed [34] Yuan et al. [35] reported a reasonable outcome follow up of PTELD in CaLDH in 50 patients and 52 patients with uncalcified LDH with a statistically significant operative time duration increase with report of neck pain incidence.

Spinal epidural lipomatosis (SEL) is a condition of overgrowth of adipose tissue within spinal canal which can be either asymptomatic or can present with symptoms of canal or foraminal stenosis [36]. Obesity is thought to be the most common cause of SEL. Incidental durotomies are also reported more up to 9.4% in obese patients. Though exact details of technical difficulties were not mentioned but anatomical obscurity is reported [37]. While doing PTELD in patients with more epidural fat, the fat pops into the operating field and obscures

visibility and bleeding at times and may make the end point of decompression fallacious [15]. So, to keep the field clear, more irrigation pressure is needed, and surgical duration also increases. Prodrome was noted in 4 obese and 4 overweight patients as per BMI in our series signifying that obesity is a risk factor especially if combined with any advanced indications for PTELD surgery.

The advantages of using a gravity flow system are the easy setup and maintenance as well as a low complication profile as the pressure rarely reaches dangerous levels inside the closed cavity, although it requires change in height of bottle as level of saline in bottle is decreasing [38]. This can be overcome by use of our IMP during surgery (Figure 2C). Irrigation fluid devices with an automated pump are commonly used to control pressure or flow volume. Use of automated pump for irrigation fluid can be associated with complication of fluid extravasation into potential spaces and adjacent soft tissue planes leading to edema in laryngeal, tracheal tissue which can cause airway obstruction and has been described in allied arthroscopic surgeries of shoulder [39].

In a study by Wu and Guan [40] comparing the effect of gravitational vs automated pump method in PTELD, a less surgical duration, intra-operative blood loss and low rate of complication in perfusion pump group has also been reported. They suggested use of automated pump with optimal pressure of 60–80 mmHg and fluid flow at 80–100 mL/min for clear intra-operative vision during PTELD. In one case each of our series, automated pressure pump and larger diameter working channel endoscope was used before a trial of procurement plan for institute. In the case with the automated pump the standard pressure recommendation was 150 mL/min [5]. Still, it led to prodrome, and it utilized 16.2 L of irrigation fluid. In a similar fashion in a case where larger diameter working channel (4.3 mm) the prodrome developed (11.4 L of irrigation fluid). The fluid used was more than usual in both. So, it is inferred that with FESS in LA, automated pumps are to be carefully used and larger channel endoscope will use more fluid to maintain better operating field.

Two studies from same institute reported about neck pain (n=8) in monitored quantified cervical epidural pressure in PTELD in irrigation with automated pump. Their average time of onset of neck pain was 17–52 minutes (34.37±11.71) [5,12]. This itself suggests the effect of an automated pump can be devastating. In our study the time of onset of prodrome was quite late in all the patients (n=8, 64.3 minutes) in gravity method with IMP. But, in our one patient with pump trial (3rd case), the symptoms started at 33 minutes (pump was then

abandoned) and again after corrective measures and restarting re-developed prodrome at 79 minutes on carrying with gravity method with IMP protocol, before finally finishing successfully after the halt at 107 minutes from start of irrigation. In the same above quoted pioneering study with a basal irrigation speed of 150 mL/min, 17.39% (n=4/23) patients complained of neck pain, while with speed of more than 200 mL/min 80% (n=4/5) patients experienced neck pain [12]. In our single case of automated pump with 150 mL/min speed, we precipitated neck pain and that too quickly at 33 minutes. It was far below the 64.37 minutes average of our other 8 patients with prodrome.

Under normal circumstances, cerebral blood flow is usually tightly auto regulated. With rise in ICP, autoregulatory mechanisms of the brain will increase the blood pressure to maintain a normal cerebral perfusion pressure. This increase in the blood pressure will lead to more intra-operative bleeding, requiring surgeon to increase the fluid flow rate and increasing the duration of infusion causing an even higher ICP than before leading to vicious cycle [26]. Additionally, to reduce anxiety and pain under LA, the used conscious sedation medications can also result hypoventilation adding on raised ICP due to increasing intra-arterial carbon dioxide partial pressure [10,12].

Evolution of easier endoscopic spine surgery in form of unilateral biportal endoscopy which has separate viewing and working portal in surgical field has an advantage of allowing for outflow through a separate portal during continuous irrigation which can prevent stagnation and collection of fluid within epidural space and avoid significant rise in ETP [26].

In our study 3 patients who developed prodrome during surgery had concurrent episode of sudden increase in BP and tachycardia and one patient had bradycardia. These vital signs along with prodromal symptoms of discomfort, upper back pain, neck pain, stiffness and headache, which occurred in patients under LA during PTELD can facilitate early detection of seizures or potential ICP increases. Upper back pain/neck pain and discomfort-confusion was the commonest prodrome in our series.

When these red flag prodromes appears, all risk factors including anesthetic, surgical causes which can cause seizure should be checked and corrected immediately. Stopping the surgery, comforting the patient, managing vitals, giving anti-convulsant, restarting the surgery after 10–15 minutes, reducing infusion pressure and reducing further surgical time are the important key points in the prevention of further seizure. In all our patients, corrective measures worked and completion of surgery was possible. Two patients had repeat prodrome and needed a halt twice. Literature suggests starting

surgery at low irrigation pressure with pump, quick surgery, and keeping epidural work towards the last of the surgery and avoiding inciting any bleed to prevent prodrome as preventive measures [9,12,26]. As the epidural space gradually fills, the shrunken dural sac loses its initial compensatory ability, and a steep increase in ETP is imminent likely. This is described as exhaustion of epidural compliance [12]. Even if temporary halting of surgery is done, the ETP may come to base line but can shoot again quickly. Therefore, experimentally it is suggested that more than 30 minutes are needed to regain its full compliance [12,27]. But every time in our current study we started the procedure in 12 to 15 minutes and accomplish the surgery and end points of decompression. Our correction measures were comforting the patient, managing vitals, giving anti-convulsant, restarting the surgery after a halt with reduced infusion pressure and reducing the further surgical time. In two of our cases, we still had to halt twice after 33/79 minutes and 26/59 minutes respectively (with further working time between the two prodromes as 46 minutes and 33 minutes in those two cases) and achieve the end points of decompression. So, practically corrective measures can work and give you time to complete the surgery. A completely contradicting report with tiring laborious experience of surgeon and patient with repetitions of wait-start-wait have been observed in attempts of quick resumption of surgery following prodrome [5,12]. But we believe that with our institute's gravity method and IMP, we could still get away. This also justifies that non automated pump like ours doesn't lead to exhaustion of epidural compliance.

The presence of fluid in epidural space was pathognomic finding in all the 9 cases. This fluid was present on 3.8 spinal segment levels proximally on average in our study. It signifies that a fluid presence circumferentially or more than 3 levels can be a risk factor. In regular operated cases this fluid level was never noted beyond 2 segment levels and post-operative MRI is a protocol for PTELD at authors institute for 14 years. The fluid egressing extra-canalicular, in irregular pattern was also noticed in 5 cases suggesting the extravasation of fluid in adjacent soft tissue due to excess ETP which was created.

All patients had adequate decompression, immediate functional outcome, and patient satisfaction index. At the follow up period of  $9.65 \pm 9.32$  months the evaluation of functional outcomes using VAS score leg/back, the patient satisfaction index and the Macnab outcome were good to excellent in all the patients in spite of the temporary episode.

The current study has many limitations. It was only a very small number of patients and retrospective in nature, but the number of cases is still the largest reported from a single cen-

ter and looking to the rarity of seizures and methodological variations in execution at different institutes, large series of statistical significance will likely never get reported. This study is based entirely on speculation because none of the patients developed seizure, but classical prodrome features were present and thorough justification on imaging and clinical records could be done. We did not perform detail MRI studies post-operative, but only T2 sagittal and axial studies. The acquired MR images were within 3 hours of surgery and substantial time delay would have given the fluid a chance to egress into normal circulation. Per-operative MRI like X-MRI is suggested for more better imaging. But it was noted that in one of the studies of Choi et al. [5] reporting the seizures, the MRI images showed Y shaped severely exsanguinated dural sac. These were visibly extreme compressions. Also, the images were acquired in the supine position as against a surgical prone position. It's possible that the fluid position shifts in the supine decubitus position. The pathological conditions of surgical indications in our study are too less in number to have statistical significance. More of anecdotal evidence can be argued. The technical postulates on 4.3 mm working channel endoscope and automated pressure pump were made on just one case each and there may be unintended technical fallacies while execution by author due to non-familiarity. The irrigation method was non-standardized though commonly used gravity method. Moreover, the IMP was again, an error prone method to document and cannot be objectified to true pressure values to arrive at linear correlations. No electro encephalogram and MR scan of brain was done immediate to confirm impending electrical activity or identify pathological changes in MRI brain. Finally, the results of the current study may not be generalizable to patients operated by PIELD or UBE. But, still looking to the rarity of the seizure complication and pure intentions to avoid it, the accepted prodromes, risk factors and technical knowhow discussed here will contribute to the literature in the exponentially evolving field of FESS. Available literature is tabulated with salient description and remarks (Table 4).

## CONCLUSION

Occurrence of prodromal symptoms should be considered as red flag sign for avoidable seizure activity and alert surgeon during PTELD. Duration of surgery and infusion fluid flow rate are associated controllable risk factor during surgery. Potential factors increasing them should be born in mind. Anecdotal reports don't constitute evidence, further large data pooling is needed for conclusive guidelines.

**Table 4.** Review of the available literature on seizure episodes and prodromal symptoms in fully endoscopic spinal surgery

Author	Technique (TF/IL/UBE)	No. of patients (age/sex)	Co-morbidities	Anesthesia	Prodromal manifestation		Seizure manifestation Symptoms and signs	Intra-operative IoP/post / post-operative PoP	Remarks/ recommendations
					Symptom	Sign			
Wu et al. [7] (2020)	TF	n = 1 (58/M)	None	GA	NC	NC	GTCS/HTN	PoP	- Keep irrigation flow < 150 ml/hr - Keep irrigation pressure: 25–30 mmHg - Perform surgery in LA as the patient can give a warning - Avoid and look out for any dural tear - Avoid intrathecal dye injection - Keep sevoflurane MAC < 1.5 - Avoid and look out for any dural tear - Keep operative time and speed of irrigation lower - Avoid dural tears, if noticed do not prolong surgery.
Kertmen et al. [8] (2016)	TF	n = 1 (20/F)	None	GA	NC	NC	GTCS	PoP	
Kim et al. [11] (2011)	NC	n = 1 (67/F)	HL/HTN	GA	NC	NC	GTCS	PoP	
Zhou et al. [9] (2018)	TF	n = 1 (26/M)	NC	LA	1. Saddle dysesthesia 2. Neck pain 3. Severe back pain	Sudden rise in BP	Limb convulsion: focal seizure/HTN	IoP	- Decrease surgical time (especially after opening the ligamentum flavum) - Set lower infusion pressure - Stop cefazolin use - Titrated use of sevoflurane - If the Cushing triad sign appears: hyperventilate
Lin et al. [10] (2020)	IL	n = 3 1. 58/M 2. 22/M 3. 60/F	None	GA	1. Sudden rise in BP 2. Sudden rise in BP 3. Sudden rise in BP				

(Continued to the next page)



Table 4. Continued

Author	Technique (TF/IL/UBE)	No. of patients (age/sex)	Co-morbidities	Anesthesia	Prodromal manifestation		Seizure manifestation Symptoms and signs	Intra-operative IoP/post / post-operative PoP	Remarks/ recommendations
					Symptom	Sign			
Choi et al. [5] (2011)	1. TF	n = 4 1. 43/M 2. 39/F 3. 43/M 4. 61/M	None	LA	1. Headache, clum- siness, visual disturbance, neck pain	NC	3 Patient: GTCS 1 Patient: focal seizure	1. IoP 2. IoP 3. PoP 4. IoP	- Decrease surgical time - Keep pressure low after controlling epidural bleed - Outflow stoppage of endoscope instead of increase in flow pressure for clear vision - Surgery in LA - Keep flow between 45- 137 mL/min
	2. IL				2. Headache, clum- siness, visual disturbance, neck pain, dizzi- ness, extremity weakness				
	3. TF				3. Neck pain, chest pain				
	4. TF				4. Headache, neck pain				
Joh et al. [12] (2009)	Cervical epidural pressure study (n = 33) TF	n = 8 had prodrome symptoms	NC	LA	Neck pain, back pain usually at the end of the procedure	NC	NC	NC	- Total time of operation and infusion had a strong correlation with onset of prodromal symptoms - Statistically significant correlation between maximal epidural pres- sure and irrigation speed/total operation time - Stop procedure for 30 minutes at onset of prodromes - Non-epileptic seizure occurred. Patient devel- oped reverse Takotsubo cardiomyopathy - Acute onset of revers- ible left ventricular (LV) dysfunction - ST-segment elevation - Minor elevation in se- rum levels of cardiac enzymes - Biportal outflow help to avoid rise in cervical epidural pressure
Shin et al. [6] (2010)	NC	n = 1 (67/F)	None	GA	None	None	GTCS	PoP	
Kang et al. [26] (2020)	UBE (n = 20) Fluid dynamics study	n = 20	NC	GA	None	None	None	NC	

NC: not classified, TF/IL/UBE: transforaminal/interlaminar/unilateral biportal endoscopy, GA/LA: general/local anesthesia, HTN: hypertension, BP: blood pressure, HL: hyperlipidemia, GTCS: generalized tonic clonic seizures.

## NOTES

### Ethical statements

All the procedure involving human participant were in accordance of 1964 Helsinki declaration and its later amendments. This is an retrospective observational study and therefore, does not need an ethical committee approval.

### Conflicts of interest

Ajay Krishnan is the Editor of the Journal of Minimally Invasive Spine Surgery and Technique and was not involved in the review process of this article. All authors have no other potential conflicts of interest to declare relevant to this article.

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# Full Endoscopic Translaminar Approach Using 7 mm Working Endoscope for High Up Migrated Disc Herniation with Severely Collapsed Disc Space: Technical Note

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The clear indication for the transforaminal approach is simple or low migrated lumbar disc herniation (LDH). The incidence of migration of the disc fragment in LDH varies from 35% to 72%. The high up migrated disc herniation into MacNab's hidden zone remains technical challenge. We provide a technical note of seldomly performed full endoscopic translaminar approach with its potential indications. A 52 years male patient presented with low back pain with left lower limb radiculopathy for 2 months. Visual analogue scale for back and leg was 2 and 8, respectively. MRI examination revealed high up migrated disc herniation with collapsed disc space at L4-5. Dynamic radiograph was not showing any instability. Based on the preoperative surgical planning working cannula was docked over left L4 lamina perpendicular to horizontal plane. With the help of 3.5 mm endoscopic burr translaminar keyhole was drilled in a concentric manner. The distance between lateral margin of pars and keyhole was intermediately inspected for preservation of adequate bone in pars interarticularis. Though the translaminar key hole subluxated tip of SAP, up-migrated disc fragment was removed. The VAS score of leg reduced significantly from 8 to 2 in immediate postoperative period. At the end of 6 months follow up period patients leg symptoms completely improved with minimal back pain. We measured the width of remaining pars postoperatively and found to be 5 mm. The full endoscopic translaminar approach is valid alternative approach for the high up migrated HNP.

**Key Words:** Full endoscopic spine surgery, Translaminar approach, MacNab's hidden zone, Migrated disc herniation

## INTRODUCTION

Endoscopic spine surgery has evolved over last few decades due to constant improvement in the optics, endoscopic instruments and technique. The full endoscopic transforaminal approach rapidly gained popularity due to its minimal invasive approach, ability to performed under Local anaesthesia, shorter hospital stay and early rehabilitation [1]. However, the

clear indication for the transforaminal approach is simple or low migrated lumbar disc herniation (LDH). The L5-S1 LDH, high grade migrated LDH and coronal deformity with Significant foraminal stenosis are relative contra indications for the transforaminal approach due to various bony obstacles. The incidence of migration of the disc fragment in LDH varies from 35% to 72% [2,3]. Many spine surgeons modified transforaminal approach to reach the migrated disc fragment such as out-



side in technique, foraminoplasty or transpedicular approach etc.; with various degree of success. However high up migrated disc herniation into MacNab's hidden zone remains technical challenge due to presence of bony and neural obstacles. Application of same endoscopic principles to interlaminar approach expanded the spectrum of pathologies which can be tackled with ESS. As compared to transforaminal approach the interlaminar approach is much anatomical and versatile. The following case report describes the patient with high up migrated disc herniation with severely collapsed disc space managed with full endoscopic translaminar approach. We provide a technical note of this seldomly performed endoscopic procedure with its potential indications for use.

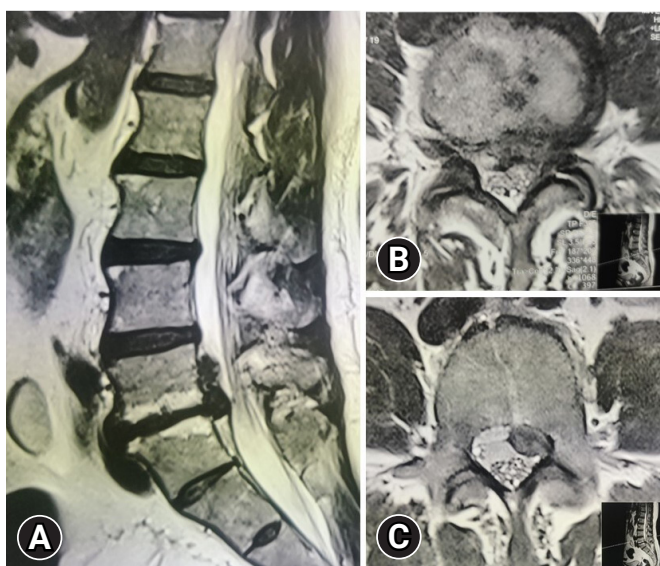
## CASE REPORT

A 52 year male patient presented with low back pain with left lower limb radiculopathy since 2 months. Patients pain severity on visual analogue scale for back and leg was 2 and 8, respectively. The neurological examination was normal. MRI examination revealed high upmigrated disc herniation with collapsed disc space at L4-5 disc space at L4-5 level ([figure 1](#)). Though end plate was showing type 2 modic changes, dynamic radiograph was not showing any segmental instability. Initially patient was tried with conservative line of treatment in form of analgesics, physiotherapy and epidural injection which failed to response hence, patient was planned for full endoscopic

translaminar discectomy.

## Surgical Technique

The preoperative planning is necessary for the translaminar approach. On plain AP radiograph, width of the isthmus and length of L4 lamina was measured to determine the safe dimension of translaminar keyhole which can be drilled into left L4 lamina. The lateral radiograph was examined to plan docking point and trajectory of bone drilling towards the targeted disc fragment. MRI scan was assessed for the extent and migration of disc fragment from a disc space. Procedure was performed under general anaesthesia. Patient was placed in prone position over a radiolucent table with lumbar spine in flexion. Based on the preoperative surgical planning 18G spinal needle was passed percutaneously over left L4 lamina perpendicular to horizontal plane. The appropriate trajectory and target point of the needle was confirmed in AP and lateral fluoroscopy. A needle was replaced with guide wire followed by serial dilator and finally 7 mm working cannula. A 25 degree endoscope with OD 6.9 mm, ID passed into working cannula (Vertebis; RIWOspine, GmbH, Knittlingen, Germany) and further procedure carried out under full endoscopic vision. The soft tissue dissection and hemostasis was carried out with a RF probe until outer cortex of lamina was visualized. The bony drilling was started with 3.5 mm endoscopic burr in a concentric manner. The colour change of bone was visualized from white outer cortex to red spongy bone to white inner cortex. The distance between lateral margin of pars and keyhole was intermediately inspected for preservation of adequate bone in pars interarticularis. Once the inner cortex is penetrated endoscopic hook is used to separate the ligamentum flavum from under surface of L4 lamina. The ligamentum flavum and subluxated tip of superior articular process is resected with endoscopic punches. The scope was partially advanced into the keyhole for better visualization and accessibility. The bleeding from lateral recess and foramen was controlled with RF probe. The subligamentous part of disc herniation was teased out with the help of endoscopic hook and expelled fragment was removed with the forceps. The hidden zone was explored with the help of flexible instruments such as RF probe and articulated forceps. The loose disc fragment underlying the exiting nerve root was pulled into operative field with flexible forceps and later removed under endoscopic vision. The final decompression was verified with free floating traversing and exiting nerve root along with empty axillary space. An endoscope is withdrawn slowly to examine the translaminar keyhole, intramuscular bleeding points. The



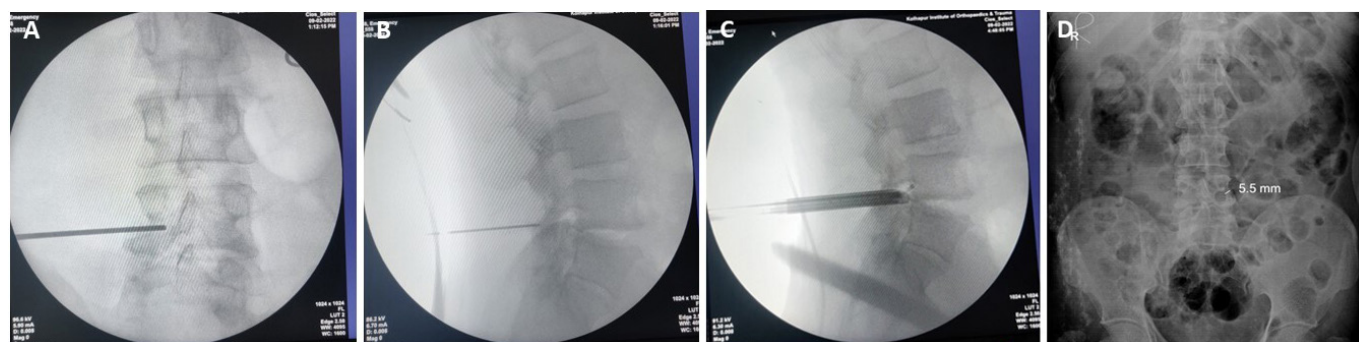
**Figure 1.** (A) Sagittal and (B, C) axial T2 image showing high up migrated L4-5 disc herniation into left MacNab's hidden zone with collapsed disc space and end plate modic changes.

wound was closed with a single stitch. The VAS score of leg reduced significantly from 8 to 2 in immediate postoperative period. Patient was ambulated from day 1 with corset belt. At the end of 6 months follow up period patients leg symptoms completely improved with minimal back pain (figure 2).

## DISCUSSION

The full endoscopic transforaminal approach has evolved over last 2 decades for management of degenerative disc diseases. However, there are some limitations for the approach due to presence of natural anatomic barriers [4]. A high-grade migration of disc imposes greater difficulty for the transforaminal approach due to presence of exiting nerve root cranially and pedicle caudally. The incidence of fragment migration in HNP varies from 35% to 72% [2,3]. Lee et al. [5] classified migration of the disc depending upon the extent of migration into near migrated disc and far migrated disc herniation. Also, they concluded that open microdiscectomy may give superior results compared PTED for far migrated disc herniation. Uniyal et al. [6] first described transpedicular approach for high down migrated disc herniation. Similarly, various spine surgeons tried transpedicular approach with significant success rate [7-9]. Kim et al. [10] narrated 3 routes of transforaminal approach to approach the high migrated HNP. The development of posterior interlaminar approach by Ruetten et al. [11,12] has expanded the spectrum of lumbar pathologies which can be managed with full endoscopic technique. However, the up migrated HNP into hidden zone remains a technical challenge for the transforaminal approach. Though it can be managed with the interlaminar approach; it needs extensive bony drilling which increases soft tissue resection and surgical time. Di Lorenzo et al. [13] first proposed the translaminar approach using

microscope in 1998 which was later supported by case series by Soldner et al. [14] in 2002. The critical comments for the translaminar approach were technical difficulty of a technique, inability to clear the disc space and iatrogenic fracture of pars interarticularis. All these difficulties can be overcome with the use of working endoscope as done in this case. It improves the visualization through translaminar keyhole which reduces the amount of bone resection and effectively chance of iatrogenic pars fracture. In 2012, Dezawa et al. [15] reported percutaneous endoscopic translaminar approach (PETA) for disc herniation with satisfactory results. Lin et al. [16] published preliminary results of 13 patients having high (n=8) and very high (n=5) grade migration. The mean operative time was 79.2 minutes with 92.3% of success rate. The operative time for the current case report was 98 minutes with negligible blood loss. We measured the width of remaining pars postoperatively and found to be 5 mm. According to Papavero and Kothe [17] at least 3 mm lateral border of pars need to be spared to avoid delayed pars fracture. The 25-degree optical angle of endoscope allows the clear visualisation of the hidden zone between the exiting nerve root and dural sac. The articulated instruments helped to deliver the fragment lying inferior to the exiting nerve root. As the disc space was collapsed the disc space exploration was not performed. However, the subluxated tip of superior articular process compressing on exiting nerve root is resected. The annuloplasty was performed with RF probe. The advantages of the translaminar approach are 1. It is minimal invasive; 2. It has shorter operative time as compared to routine translaminar approach; 3. Shorter hospital stay with early mobilization. The relative contra indication for present technique is LDH associated with ligamentum flavum hypertrophy, moderate to severe canal stenosis or facet cyst which absolute the use of interlaminar approach [18]. The key surgical points while perform-



**Figure 2.** (A) Intraoperative fluoroscopic AP and (B) lateral image showing precise docking of spinal needle over left L4 lamina. (C) Intra-operative lateral fluoroscopic image showing partial advancement of bevel into keyhole. (D) Postoperative AP radiograph showing keyhole with preservation of pars interarticularis (5.5 mm).

ing translaminar approach are 1. Precise docking of working cannula over target point; 2. Maintaining accurate trajectory of concentric drilling with preservation of lateral bony bridge; 3. The exiting nerve root decompression with the help of flexible forceps with minimal neural retraction [19]. It can be applied for down migrated disc herniation; however modified transforaminal approach or transpedicular approach can be used with the same precision. Current technique has its own limitations such as it has significant learning curve and limited indication, it needs precise docking and trajectory of bony drilling to reach the migrated fragment of disc and possibility of intra/postoperative pars fracture cannot be ruled out.

## CONCLUSION

The full endoscopic translaminar approach is valid alternative approach for the high up migrated HNP. It has certain advantage over routine interlaminar approach as it preserves the motion segment with shorter operative time. However, the technique has significant learning curve with limited indications.

## NOTES

### Ethical statements

The patient and relative has given informed written consent for the submission of a case report to the journal.

### Conflicts of interest

Hyeun-Sung Kim is the Editor-in-Chief of the Journal of Minimally Invasive Spine Surgery and Technique and was not involved in the review process of this article. All authors have no other potential conflicts of interest to declare relevant to this article.

## Supplementary Materials

Supplementary Video 1. Full endoscopic translaminar approach for far up migrated L4-5 disc herniation. (<https://doi.org/10.21182/jmisst.2023.00682.v001>)

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# Management of a Rare Case of C2–3 Cervical Foraminal Disc Herniation by Unilateral Biportal Endoscopic Foraminotomy

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Foraminal disc herniation at the C2–3 level is a very rare entity, for which a consensus treatment protocol has not been established. This case report explains that unilateral biportal endoscopic foraminotomy is a very effective, minimally invasive, and safe procedure for this condition. A 62-year-old woman presented to our clinic with complaints of a 6-week history of posterior axial neck pain and sudden onset of hypoesthesia over the right periauricular region, face and lip. Magnetic resonance imaging (MRI) revealed C2–3 right foraminal disc herniation, and posterior cervical foraminotomy was done using the unilateral biportal endoscopic technique. The patient reported complete relief of the axial neck pain soon after surgery and gradual improvement of the hypoesthesia. Postoperative MRI showed complete removal of the compressing disc fragment. In conclusion, this case shows that a minimally invasive biportal endoscopic procedure can be a better choice for decompression than many extensive and destructive procedures. This is the first case report in the literature describing the management of C2–3 foraminal disc herniation by posterior cervical unilateral biportal endoscopic foraminotomy.

**Key Words:** Intervertebral Disc Displacement, discectomy

## INTRODUCTION

The disc herniation incidence at C2–3 level is relatively not that common when compared to that of its occurrence in the subaxial cervical spine. Therefore, early diagnosis can be difficult for the clinicians and there are high chances that this can go undiagnosed. Even after diagnosing a C2–3 disc herniation, many spine surgeons are relatively very inexperienced in performing any sort of minimally invasive surgery at this level as it can be very challenging. Various extensive and traumatic surgical techniques like the Cloward's technique [1], transoral odontoidectomy with or without occipitocervical fusion [2,3], anterior discectomy with fusion [2,4], far lateral approach [1,5], posterior transdural approach [6-8], anterolateral extradural

approach [9] have been used to address the C2–3 disc herniation. Since these described techniques are very extensile and destructive ones, so a lot of disadvantages goes with it. Hence, we herein report a safe and minimally invasive procedure in the form of posterior cervical unilateral biportal endoscopic foraminotomy technique for addressing the C2–3 foraminal disc herniation.

## CASE REPORT

### 1. History

A 62-year-old female presented in the outpatient clinic of our hospital with complaints of 6 weeks duration posterior axial

neck pain and sudden onset hypoesthesia over the right preauricular region, face and lip. The patient initially had relief of the posterior neck pain on taking analgesics and doing physiotherapy but later did not have any significant improvement. The intensity of the neck pain increased during the off period from analgesics and now even after taking analgesics there is no relief at all in her neck pain.

## 2. Examination

On performing neurological assessment, the patient was not able to move her head owing to the severity in pain. She was in complete distress as there was no resolution in the pain and her sleep was seriously affected for many days. All her neck movements were restricted due to pain but did not show any myelopathic symptoms or signs. Magnetic resonance imaging of the brain was normal but that of the cervical spine showed a C2–3 level foraminal disc herniation that was compressing the right C3 root ([Figure 1](#)) which indicated the need for surgery.

## 3. Surgical Technique

### 1) Equipment's Used in Biportal Endoscopic Cervical Foraminotomy

\*4.0-mm diameter zero-degree arthroscope

\*4-mm solid diamond burr

\*4-mm shaver with protective sleeve

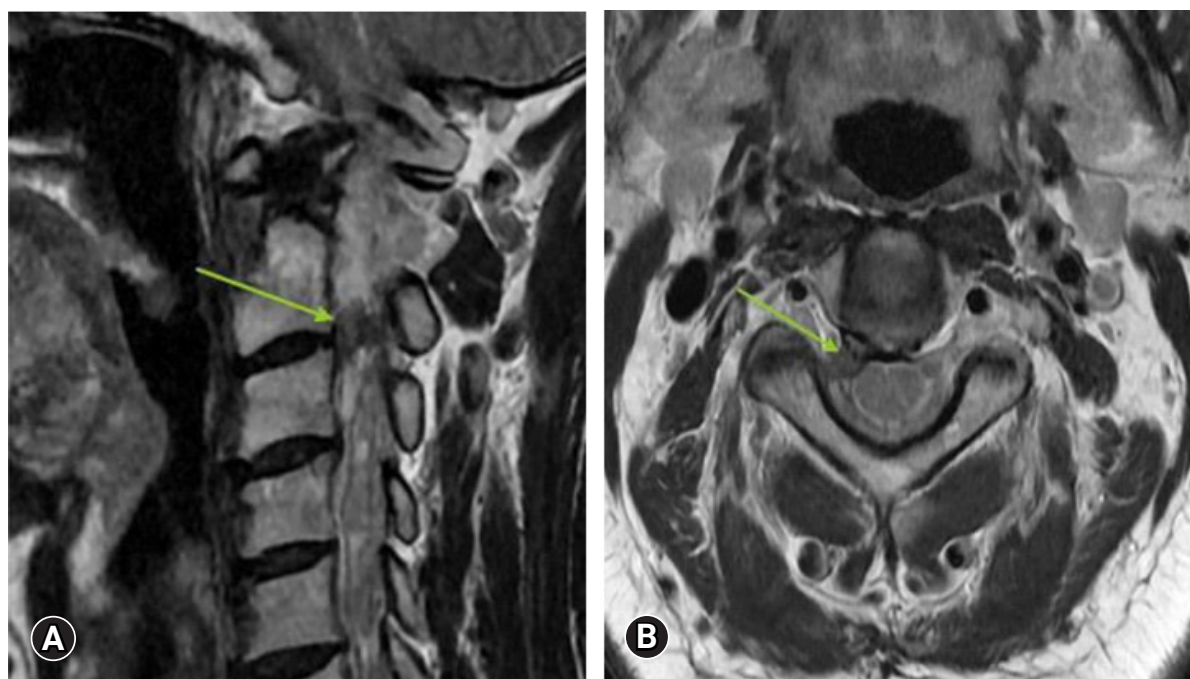
\*3.75-mm ninety-degree radiofrequency ablator and 1.4 mm thirty-degree micro ablator radiofrequency probe for controlling intraoperative bleeding

\*Serial dilators

\*Commonly used foraminotomy instruments like 1 mm & 2 mm Kerrison punches, 1.5 mm standard and upbite pituitary forceps, nerve hook (ball tip probe) and small curettes.

### 2) Surgical Steps

For the surgery, patient taken in prone position after giving general anesthesia. The H shaped pillow was used to relax the abdomen so as to avoid an increased abdominal pressure. The eye ball and face were protected from direct high pressure using a gel type facial pad. The neck kept in flexed position and upper back to the slanting down manner to get a good venous return and thereby reduces the chance of excessive intra operative bleeding. The head was fixed in flexed position and both the shoulders were pulled and fixed with a plaster tape. No head rest or any cervical traction kit was used. With strict aseptic precautions, sterile painting and draping of the entire posterior neck was done. Since the lesion was on the right side and the surgeon right handed, so the surgeon stood on the left side ([Figure 2A](#)). Under C-arm fluoroscopy guidance, C2 and C3



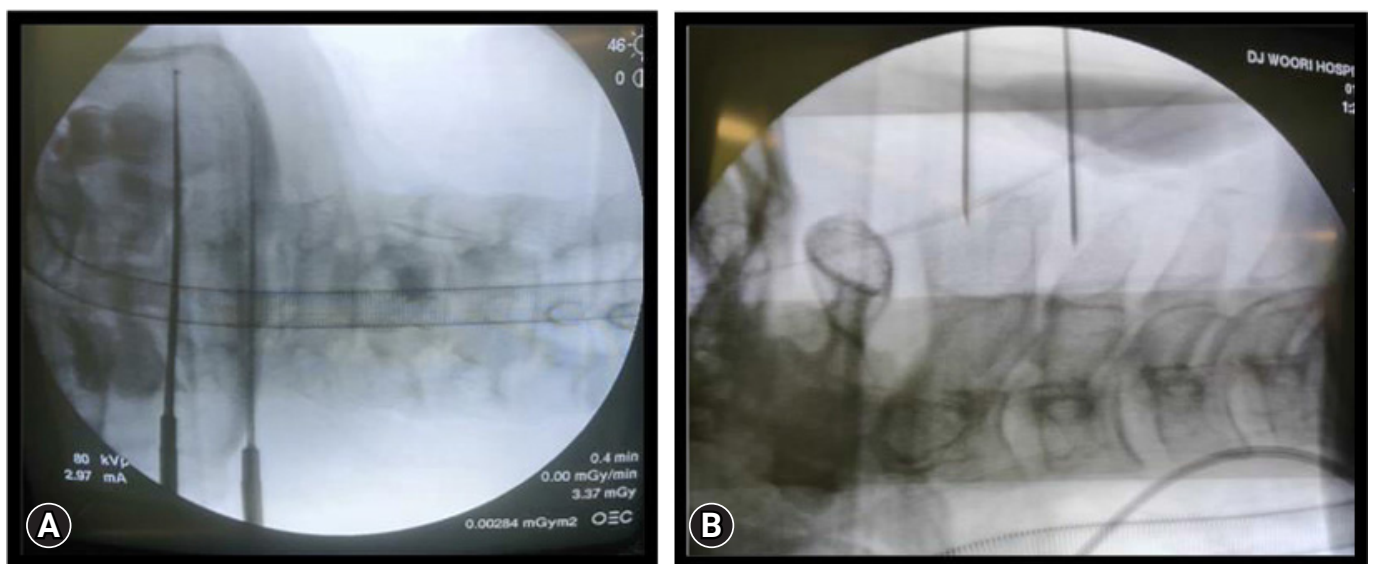
**Figure 1.** Magnetic resonance imaging. (A) Sagittal view showing a herniated disc, marked by an arrow mark. (B) Axial view showing foraminal disc herniation at the C2–3 level compressing the right C3 root, marked by an arrow mark.

pedicles were marked (Figure 3). Each 0.5 cm long two transverse skin incisions each made along the marked pedicles. The caudal skin incision over the lower pedicle was for the working portal and the cranial skin incision over the cranial pedicle was for the scope portal. An approximate of 2 cm distance was kept between both the portals. In order to achieve the required operative space, serial dilators were used for neck muscle dissection. A cannula and then a zero-degree scope was inserted through it from the cranial scopic portal. A proper natural saline irrigation system through the operative area was confirmed. No saline pressure pump was used instead the height of the saline bag holding stand was kept at 1.6 m from the floor. Now, through the caudal working portal, surgical instruments were inserted. After triangulation of the instruments and endoscope at the target V point (that is on the margin of the superior lamina, inferior lamina and the medial point of facet joint), the radiofrequency probe was used to clear the soft tissue remnants and control the minor bleedings. After thoroughly delineating the V-point, next is to drill out the portion of superolateral part of the lower lamina, inferolateral portion of the upper lamina (Figure 2B) and medial point of the facet joint (V-point) using a 4 mm diamond burr. It was done until ligamentum flavum of caudocranial margin was exposed. The ligament flavum was preserved throughout the drilling for laminotomy to protect the neural structure beneath. The burr was then directed laterally for foraminotomy to the inner surface of the facet joint along direction of the root. By using a 1 mm, 2 mm Kerrison punches and small curettes, distal portion of the root can be further

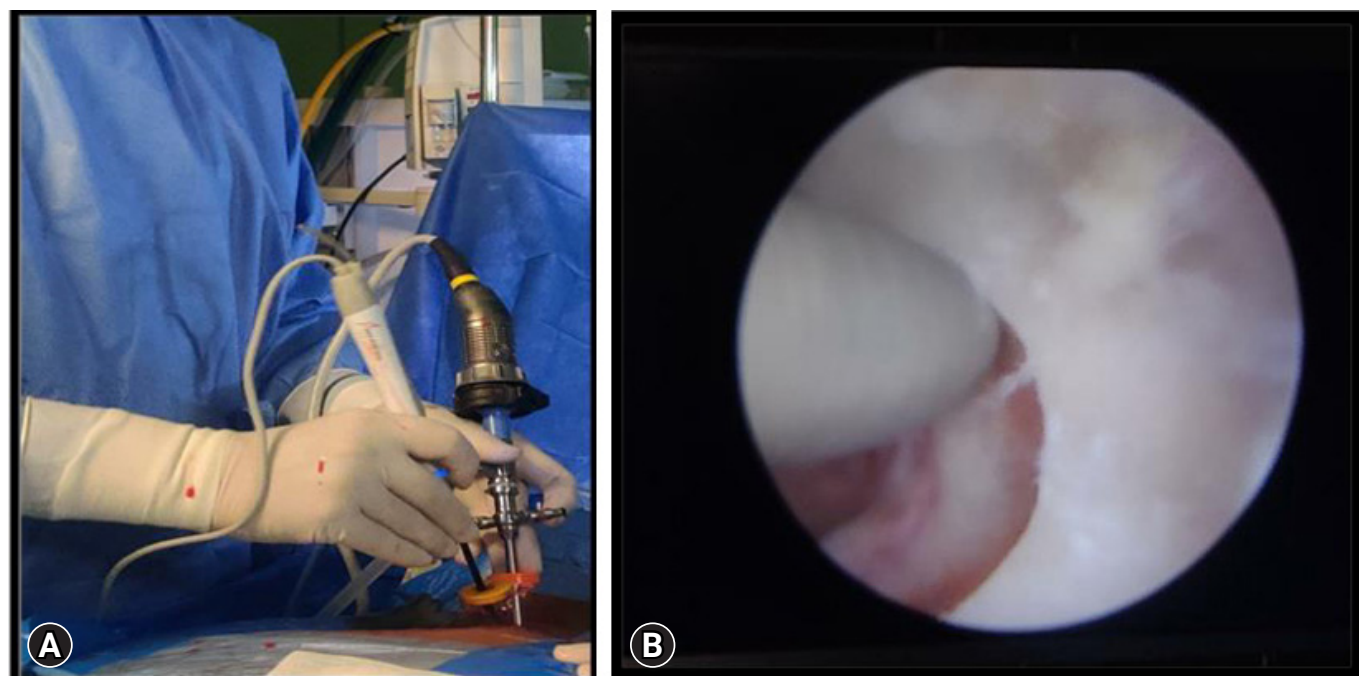
decompressed by removing the cranial tip of the SAP (superior articular process). Now after achieving enough bony decompression, the yellow ligament was removed from the thecal sac by piecemeal method along the direction of root. The small 1.4 mm thirty-degree radiofrequency ablator was used to achieve complete hemostasis around the root origin. Once a clear field was achieved, the adequacy of decompression confirmed by passing a nerve hook or ball tip probe through the foraminal canal without any resistance. Discectomy/fragmentectomy now performed using the nerve hook and pituitary forceps (Figure 4A). The cannula of the scope can be used as a protection for the root while performing this discectomy. Root is checked finally for complete decompression (Figure 4B), hemostasis confirmed and wound closed over subcutaneous suture and skin suture with hemovac drain in situ. The patient was kept on a soft neck collar for 2 weeks.

## DISCUSSION

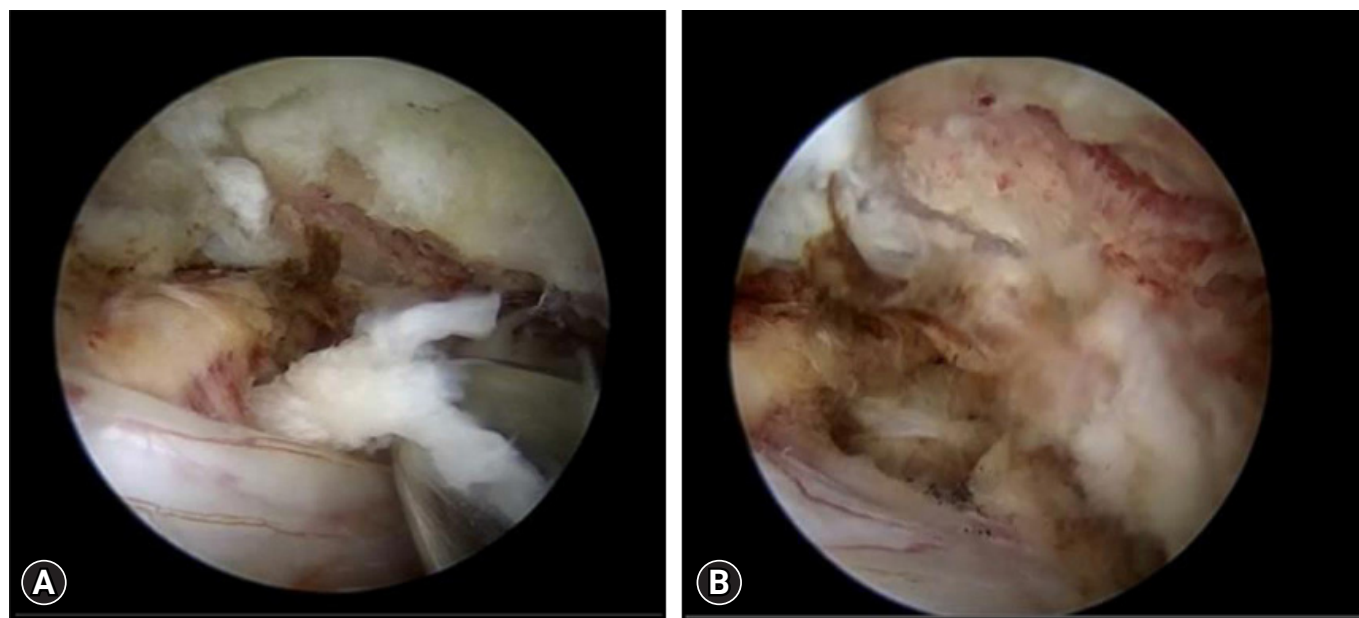
It is believed that intervertebral disc herniation results because of a long-term degenerative process happening in the disc. This C2-3 disc herniation is a rare case [7,10] since according to the present literatures available, there is less than 1% of incidence [10] and management of the same by posterior cervical foraminotomy by biportal endoscopic technique has not been described anywhere. The levels C5-6 and C6-7 are the commonly involved levels as there is maximum mobility at these lower segments and are therefore subjected to increased



**Figure 2.** (A) Surgeon standing on the left side and working on the lesion on the right. (B) Drilling the lower aspect of the cranial lamina.



**Figure 3.** C-arm fluoroscopy images. (A) Anteroposterior view confirming the level. (B) Lateral view showing two 18 G needles placed at the C2 and C3 pedicle levels before performing a skin incision.



**Figure 4.** Intra-operative images. (A) Removal of the herniated disc fragment using pituitary forceps. (B) Decompressed nerve root.

stress during movements. As the age of the patient increases, there occurs both bone and discal remodeling respectively which results in lower level disc fusion, decreased mobility of that segments and subsequently the load distribution to upper levels like C2–3 and C3–4 disc increases [7]. This contributes to

the mean occurrence of C2–3 disc herniation in elderly population [11,12]. There can be varying clinical presentations in the background of degenerative damage as its a late onset from a mere sensory or motor radiculopathy to a severe myelopathy or even Brown Sequard syndrome [4,10,11,13].

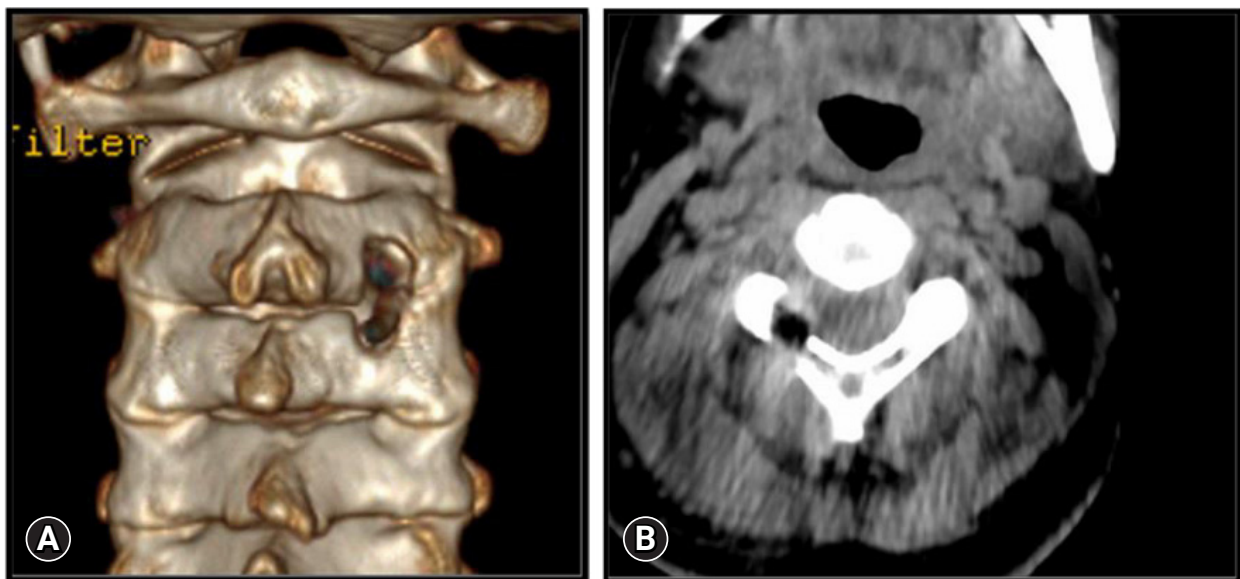


In this case, the patient did not have any classical radicular symptoms of nerve root compression instead the patient presented with not improving posterior axial neck pain of almost 6 weeks duration and sudden onset of right side periauricular, lip and face hypoesthesia.

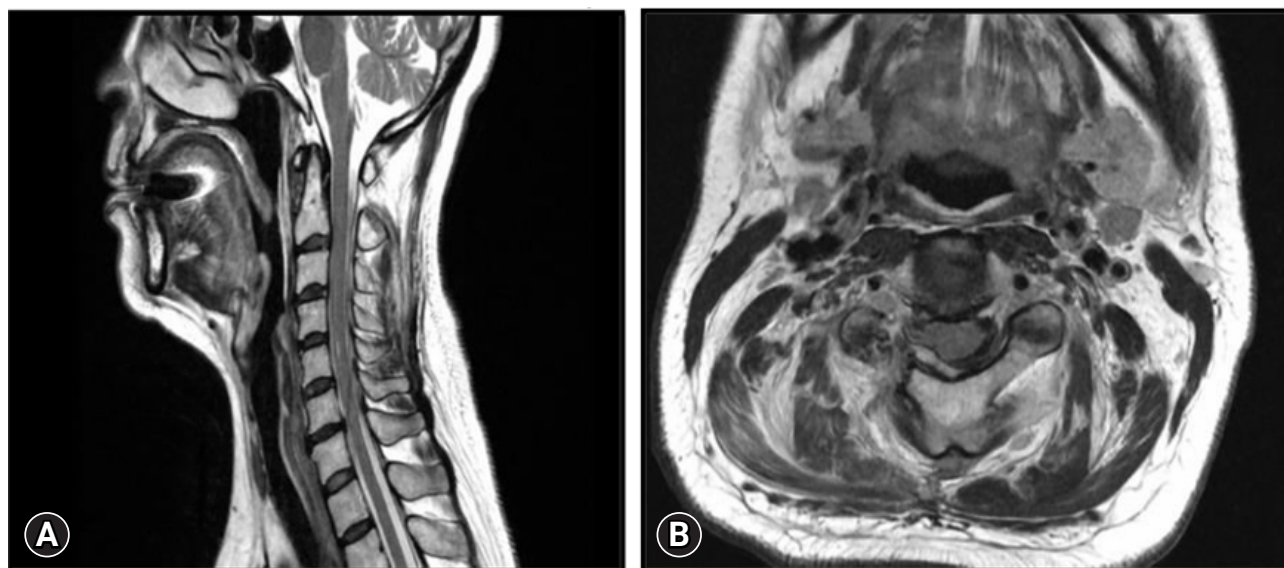
The patient was put initially on oral analgesics and steroid medications along with physiotherapy by other treating physicians since the onset of neck pain. Since the patient did not have any significant improvements in the symptom during the off period from medications and as a part of our treatment protocol to diagnose the underlying pathology, MRI (magnetic resonance imaging) of the cervical spine was done which showed a C2-3 disc herniation of foraminal type compressing the C3 nerve root. As the conservative trials did not yield any promising results, a surgical intervention was planned to give a better outcome. The most commonly practiced surgical procedures were ACDF (anterior cervical discectomy and fusion) and PCF (posterior cervical foraminotomy). Since we wanted to offer a safe and less traumatic procedure, a minimally invasive endoscopic technique with a biportal approach to conventional arthroscopic systems for spinal disease [14,15] was opted to decompress the C3 nerve root.

The rationale for choosing this approach was that a direct access could be gained to the foraminal lesion site thereby not needing to do an extensive discectomy, preserving the movement and major portion of the intervertebral disc. Since this is not a fusion procedure, so the graft related complications are avoided and reduces the chance of adjacent segment disease.

This minimally invasive cervical foraminotomy is also a better cost effective procedure than ACDF [16]. Since this biportal endoscopic surgery is carried out completely under a continuous fluid irrigation, this decreases the chance of intraoperative bleeding and also provides a clear, magnified, three dimensional vision of the operative field by the use of endoscope. This enables the operating surgeon to perform meticulous and fine manipulation around the neural structures safely. The use of radiofrequency probe also helps in significant reduction of epidural bleeding which usually creates a lot of trouble for the operating surgeon in a conventional open surgery. The second portal or the working portal allows an unconstrained, free use of various required surgical instruments thereby contributing to a better result. The other advantage of this procedure is that only targeted minimal bone resection (Figure 5) is needed and helps in achieving the clinical results comparable to that of the conventional procedures, while giving all the advantages of a minimally invasive procedure. This biportal endoscopic procedure enables a short surgical time, minimal surgical scar, rapid rehabilitation, short hospital stay, low postoperative care cost, early return to previous routine work and high patient acceptance [17]. However, the disadvantage for this technique is that it may not be helpful in addressing case of cervical instability, central canal stenosis and disc space collapse which calls for an anterior surgery for height restoration. This techniques also has a steep learning curve which needs time to master. The conventional open procedures expertise is very much needed in the field of spinal surgery and must be mastered by surgeons



**Figure 5.** Computed tomography images. (A) Coronal and (B) axial views showing the bony defects made to access the herniation.



**Figure 6.** Postoperative T2-weighted magnetic resonance imaging. (A) Sagittal and (B) axial views showing adequate decompression of the right nerve root.

so that they can tackle the problems of limited possibility to expand the surgery in the event of an unforeseen obstacles and complications which may be faced when performing full endoscopic procedures.

In the year 1996, first case of unilateral biportal endoscopic (UBE) technique was reported for treatment of lumbar discectomy [18] and the clinical results of it were published two years after in 1998 [19]. Nowadays, all spine pathologies can be addressed with this full endoscopic biportal technique similar to a conventional open method.

Postoperative radiological study (Figure 6) showed successfully removed protruded disc fragment and enlargement of the foraminal area significantly without the stability of the cervical spine being compromised. On two months clinical follow up after surgery, the patient has no neck pain and almost 50% recovery of the periauricular, lip and facial hypoesthesia. This case report shows that posterior biportal endoscopic foraminotomy technique is a good option for managing cervical foraminal disc herniation and foraminal stenosis. A long-term duration of follow up with more number of cases is indeed necessary to confirm the final outcomes.

## CONCLUSION

Posterior cervical unilateral biportal endoscopic foraminotomy technique is a minimally invasive and safe supplement which can replace the traditional extensive and destructive open procedures when the indication criteria are fulfilled.

## NOTES

### Ethical statements

Not applicable.

### Conflicts of interest

No potential conflict of interest relevant to this article.

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1. Journal of Minimally Invasive Spine Surgery & Technique (JMSST®, eISSN 2508-2043) 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). This Journal publishes important papers covering the whole field of minimally invasive spinal surgery, including studies in pain intervention and peripheral nerve disease or trauma and related surgery, neuroscience, neurology, molecular biology and biomechanics.
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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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