Ameliorated Full-Endoscopic Transforaminal Decompression for L5–S1 Foraminal and Extraforaminal Stenosis

Chang-Chen Yang, MD, PhD,*† Kuang-Ting Yeh, MD, PhD,‡§ Keng-Chang Liu, MD, PhD,†
and Wen-Tien Wu, MD, PhD*‡§

Study Design: This is a retrospective review.

Objective: To describe a modified surgical technique, full-endoscopic transforaminal decompression (FETD) in patients with L5–S1 foraminal stenosis or extraforaminal stenosis (EFS) and to detail the short-term results.

Summary of Background Data: Performing FETD surgery for L5–S1 FS and EFS is challenging because of high iliac crests in most cases and the difficulty in accurately differentiating between FS and EFS by images preoperatively.

Material and Methods: Patients who had solitary unilateral L5–S1 FS or EFS and had undergone FETD between October 2014 and December 2017 were included. In total, 22 patients underwent FETD for L5 root compressions at the L5–S1 levels. All patients were followed up for more than 1 year.

Results: The mean visual analog scale score for back and leg pain, assessed preoperatively and at 12 months postoperatively, improved from 6.3 ± 1.7 to 1.59 ± 1.30 and from 7.29 ± 0.78 to 1.41 ± 1.20, respectively. The mean Oswestry Disability Index improved from 61.53% preoperatively to 15.8% at 12 months postoperatively. Neurovascular injury–related complications were absent in all these cases.

Conclusion: Successful short-term clinical outcome is achievable using the ameliorated FETD technique for treating L5–S1 FS and EFS.

Full-endoscopic transforaminal decompression (FETD) for foraminal stenosis (FS) or extraforaminal stenosis (EFS), with or without disk herniation, has become popular in recent years. The FETD technique is widely accepted for FS decompression or far lateral disk herniation. However, performing FETD at the L5–S1 level is challenging because of the high iliac crest and hypertrophic ala in some patients.[1]

Because of certain anatomic features, L5–S1 is the most common location for FS cases. The L5 nerve root can be entrapped in both L5–S1 FS and EFS. However, magnetic resonance imaging (MRI) is not diagnostically reliable for both pathologies because of the high sensitivity of the root foramen cross-sectional area ratio to position changes.[2,3] This makes preoperative differential diagnosis between FS and EFS difficult.

Several methods have been reported for treating FS, including transforaminal lumbar interbody fusion, micro-endoscopic discectomy, FETD, and biportal endoscopic decompression surgery. Herein, we report our experiences and clinical results with FETD used exclusively for L5–S1 FS and EFS.

MATERIALS AND METHODS

Patient Eligibility

In this retrospective cohort study, we reviewed the data of patients with L5–S1 FS or EFS treated with FETD between October 2014 and December 2017. Approval was obtained from the Institutional Review Board and Ethics Committee of Buddhist Dalin Tzu Chi Hospital, Taiwan (No. B10704018), and the requirement for patients' informed consent was waived because of the retrospective study design. All patients presenting with suspected L5–S1 FS or EFS on MRI were selected, and the diagnoses were made on the basis of positive L5–S1 foraminal nerve block tests.

Twenty-two patients who underwent FETD were followed for more than 1 year; 9 had no history of spinal surgery before undergoing FETD, whereas 13 had a history of fusion above L5, with 8 having disease at a level adjacent to the prior fusion and 5 having FS or EFS that was undiagnosed during the previous spinal surgery. One patient had recurrent L5 radicular pain after a falling accident 4 years after solid L5–S1 interbody fusion (Fig. 1).

Inclusion Criteria and Outcome Evaluation

The inclusion criteria were (1) symptomatic lumbosacral FS or EFS leading to unilateral L5 radiculopathy despite > 6 weeks of conservative treatment; (2) L5 radiculopathy with FS or EFS, regardless of suspected disk herniation on MRI.

The exclusion criteria were intracanalicular stenosis, spondylolisthesis, segmental instability, pars interarticularis fracture, or coexisting pathologic condition such as infection or tumor.

Patient data were obtained from chart reviews and patient-based outcome questionnaires. Back and leg pain were evaluated preoperatively, immediately postoperatively, and at 6, 12, and 24 weeks and 1 year postoperatively. Back pain and radicular leg pain levels were assessed using the visual analog scale (VAS), and functional status was assessed using the Oswestry Disability Index. Clinical outcomes were assessed according to the modified MacNab criteria.

Surgical Procedure

A modified version of the technique described in Ahns Report for FS and EFS was used.[1] Briefly, the major steps performed included extraforaminal docking of the working cannula, foraminal unroofing, medial transverse process inferior fenestration, ligamentum flavum removal, and removal of cranially directed protruding disk or a lateral disk check, if present, and further decompression of the lumbosacral tunnel until the L5 nerve root was mobilized or loosened. The main pathologies leading to nerve compression were recorded. The surgical procedure is discussed in detail in the following sections. In addition, an instructional procedure video was linked (Video, Supplemental Digital Content Endoscopy L5S1.mp4, http://links.lww.com/CLINSPINE/A169), which demonstrates the surgical procedure with a case report.

Patient Preparation

In preparation for surgery, the patients were placed in a prone position on a radiolucent table. Xylocaine (0.5%) was used to anesthetize the skin and muscular layers, medial L5 transverse process, and foramina area. In most cases of L5–S1 stenosis, high iliac crests decrease the intraoperative range of motion of the endoscopic working cannula. To improve the surgeon's ability to evaluate the foraminal and extraforaminal spaces, the planned working cannula angle of inclination was 45 degrees in the direction of the facet joint (Fig. 2A). The

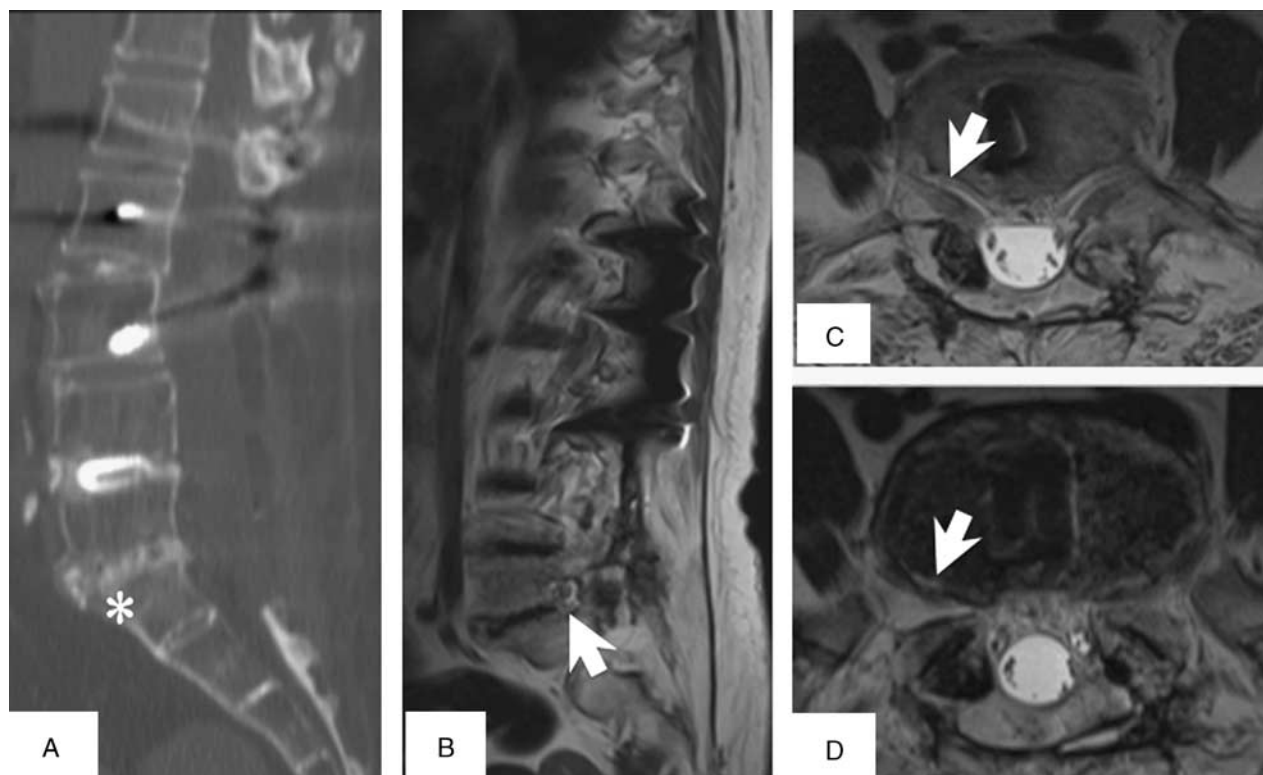**FIGURE 1.** A, Sagittal view of spinal computed tomography shows solid interbody fusion (asterisk) in a 73-year-old woman who underwent multiple spinal fusion surgeries involving L5–S1 and developed new-onset right L5 radiculopathy after a minor trauma. Sagittal view (B) and axial views (C, D) of spinal magnetic resonance imaging of the right L5–S1 foramen shows minimal compression of the L5 root at the L5–S1 level (white arrows).
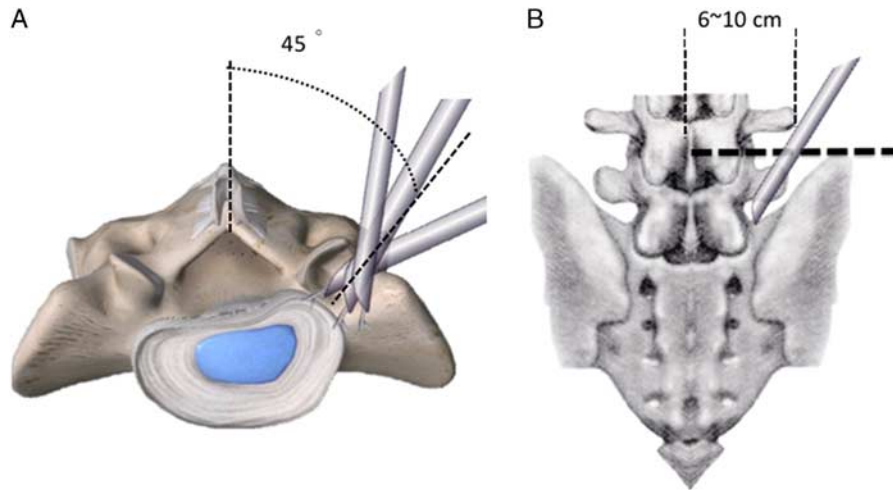
FIGURE 2. A, To check both the foraminal and extraforaminal spaces, the planned angle of inclination for the cannula in our study was 45 degrees toward the facet joint. B, The skin entry point was located at the level of the posterior iliac crest and 6–10 cm lateral to the midline, depending on the patient's waist size (dashed line). [full color online]

skin was entered at the level of the posterior iliac crest and 6–10 cm lateral to midline, depending on the patient's waist size (Fig. 2B).

Extraforaminal Docking of the Working Cannula

After administering local anesthesia, an 18-G spinal needle was inserted to target the lateral L5–S1 facet joint surface. Next, the needle was replaced by a guidewire under fluoroscopic guidance. Subsequently, a 7.0-mm-diameter dilator was inserted over the guidewire and advanced to the extraforaminal area to achieve firm engagement in the L5–S1 extraforaminal region. Then, a bevel-ended working cannula (7.0-mm inner diameter) was introduced over the dilator and placed on the lateral

undersurface of the L5–S1 facet joint, and the dilator was removed.

Foraminal Unroofing or Enlargement

Initial foraminal unroofing was accomplished using a trephine burr under fluoroscopic guidance. In this procedure, the L5 nerve root is potentially irritated, especially in patients with EFS. Therefore, if a patient experienced pain during the initial phase of trephine-assisted unroofing, the trephine was placed horizontally (Fig. 3A) to prevent L5 nerve irritation.

Furthermore, the foraminal unroofing procedure could be completed simply by using an endoscopic burr (Figs. 3B, C) even without a trephine. With or without initial trephine
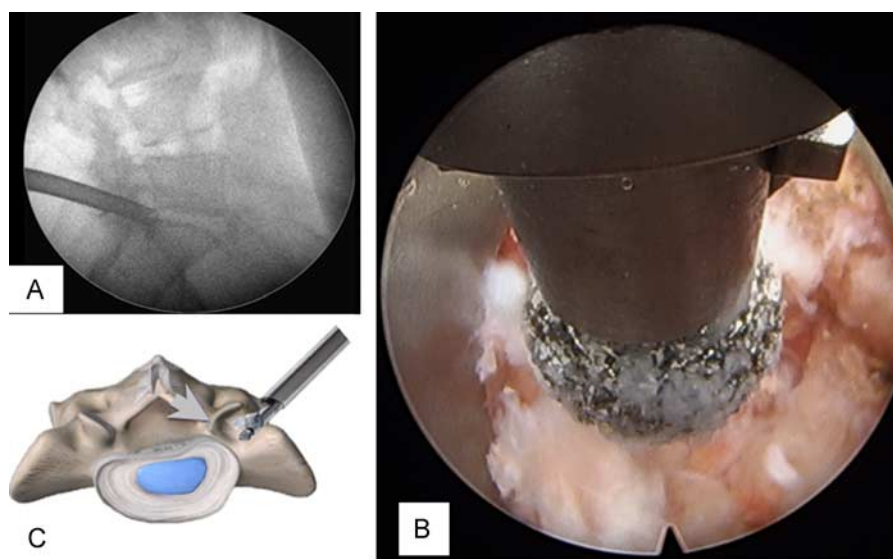

FIGURE 3. A, Initial unroofing was performed under fluoroscopic guidance using a trephine, (B) with or without initial trephine unroofing, foraminal unroofing was completed using the endoscopic burr. C, Thus, the foramen was trumpet shaped (gray arrow) to enable the working cannula to be used to check the related pathology. [full color online]
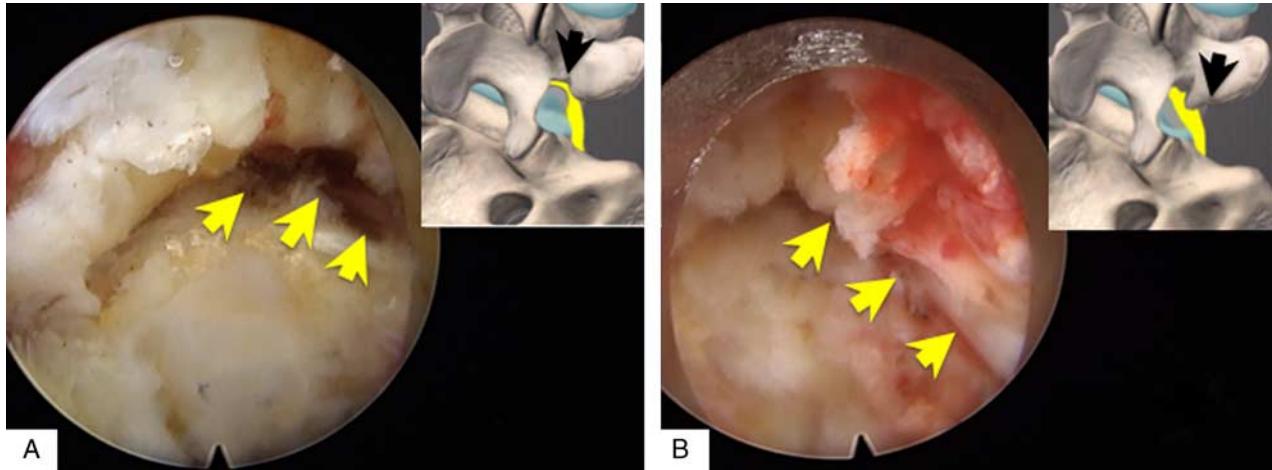
FIGURE 4. A, After removing the hypertrophic bone and ligamentum flavum, a bulging disk was identified and the L5 root was pushed upward (yellow arrows), (B) in some cases, transverse processes had to be partially removed (black arrow) to expose more of the nerve root. After removing the upward bulging disk, including the annulus fibrosus, the L5 root (yellow arrows) was moved downward and freed from compression. Insets in 4A and 4B: Zoom out view of L5S1 foraminal region. [full color online]

unroofing, foraminal unroofing could be performed completely using an endoscopic burr. After a bevel-ended working cannula was placed over the lateral portion of the S1 facet, a 30-degree spinal endoscope (SPINENDOS GmbH, Munchen, Germany) was placed. Then, a 3.7-mm-diameter endoscopic burr was inserted through a 4.3-mm working channel to complete the unroofing process.

Bone removal was begun from the lateral border to the inferior portion of the S1 superior facet joint, including the part of the cranial-lateral border of the S1 pedicle base. In patients with high iliac crests, approximately a 5-mm-wide medial–caudal portion of the L5 transverse processes could be partially removed using an endoscopic punch to expose the underlying structures (Fig. 4). After the hypertrophied superior facet had been undercut, intraforaminal structures, such as the

foraminal ligament and ligamentum flavum, were clearly exposed. Subsequently, the ligamentum flavum was removed using an endoscopic punch until the epidural fat covering the exiting nerve root was exposed.

At this point, the working cannula and spinal endoscope were placed in the widened extraforaminal and intraforaminal spaces around L5–S1. By moving the cannula between 30 and 80 degrees and rotating the beveled working channel, a sophisticated exploration was performed from the inner portion of the interforaminal space through the extraforaminal space to the lumbosacral tunnel. With the working cannula horizontally placed, the interforaminal space around L5–S1 could be checked. Furthermore, by holding the cannula vertically, the extraforaminal and outer L5–S1 spaces could be examined (Fig. 2).

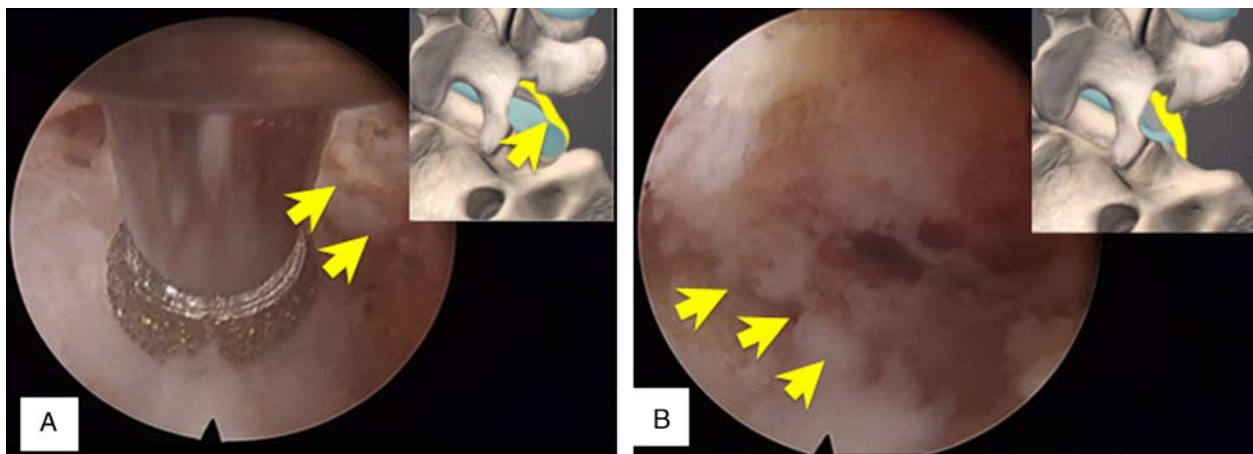**FIGURE 5.** A, The calcified disk bulging was pushing the nerve root (yellow arrows) laterally, leading to extraforaminal stenosis, and an intraoperative burr was used to remove the disk. B, After the calcified disk had been removed, the L5 dorsal root ganglion (yellow arrows) was moved medially and freed from tension. Insets in 5A and 5B: Zoom out view of L5S1 foraminal region. [full color online]
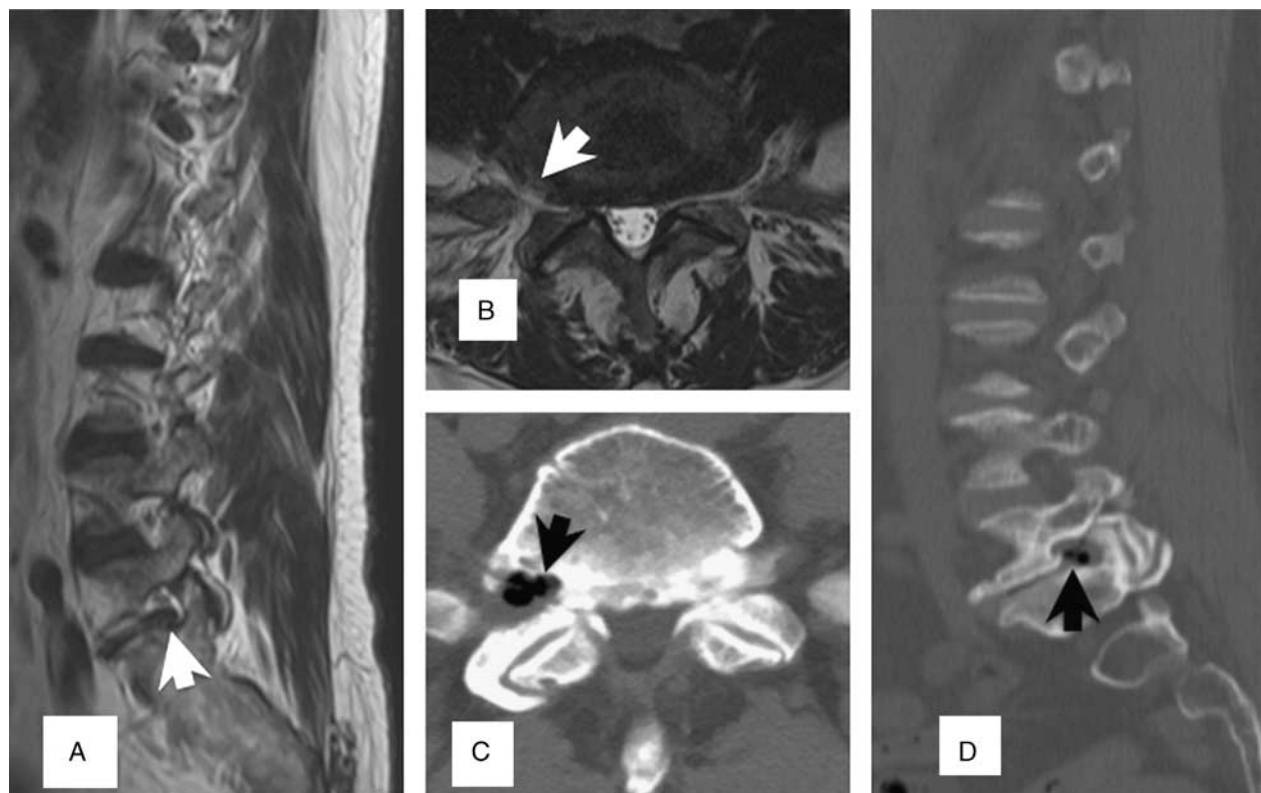
FIGURE 6. A and B, Preoperative magnetic resonance imaging (T2 sagittal and axial views of the L5–S1 foraminal region) in a 56-year-old woman with L5 radicular pain for 5 years shows low-grade foraminal stenosis (white arrows). C and D, Postoperative computed tomography shows an enlarged foraminal space after removing the calcified bulging lateral disk (black arrows).

Endoscopic Disk Removal

Part of the L5 nerve root was exposed after the initial unroofing. Then, the upward or lateral bulging disk was checked. In some cases, even in the absence of a severely hypertrophic S1 facet joint, the exiting nerve roots were compressed by upward bulging disks in foraminal regions (Fig. 4) or lateral bulging disks in S1 pedicle base regions (Figs. 5, 6). Decompression could be accomplished by removing the upward bulging annulus fibrosus and disk content by using endoscopic graspers and punches. In cases of calcified disk herniations, the endoscopic burr was used until the exiting nerve was freed from the tenting (Fig. 6). Finally, the lumbosacral tunnel was checked by holding the cannular at nearly 90 degrees; the hypertrophic sacral ala (Figs. 7B, C) was removed by using a burr or punches if lumbosacral tunnel stenosis was identified intraoperatively. The surgeon could identify and mobilize the exiting nerve root by moving or rotating the bevel-ended cannula under endoscopic visualization from the infrapedicle region to the lumbosacral tunnel. The end point of the procedure was free mobilization of the exiting nerve root. After achieving adequate hemostasis with a bipolar coagulator, the endoscope was withdrawn, and sterile dressing was applied using a 3-0 suture. Postoperatively, the patient remained in hospital for 1–2 days before discharge.

Statistical Analysis

Comparisons were performed between preoperative and postoperative clinical outcomes in pain and functional status. The Mann-Whitney U test was used as a parametric test to compare means repeated over time. SPSS for Windows (version 22.0, SPSS Inc., Chicago, IL) was used for all statistical analyses, and $P < 0.05$ was considered statistically significant.

RESULTS

Twenty-two patients (18 women, 4 men) with a mean age of 64.6 years (range, 50–77 y) underwent percutaneous endoscopic decompression for L5 nerve root decompression.

The mean operative time was 96.3 ± 23.5 minutes (range, 43–126 min), and the mean body mass index (BMI) of the patients was $26.9 \pm 4.1 \text{ kg/m}^2$ (range, 18.6–34.8 kg/m²). On the basis of the MacNab criteria, the surgical outcomes were excellent in 10 patients, good in 9, fair in 3. Patients were followed for at least 1 year (mean, 22.7 mo; range, 12–45 mo). The mean VAS score for back pain were as follows: preoperative, 6.3 ± 1.7 (range, 8.5–4.5); postoperative, 0.9 ± 0.78 (range, 4.0–1.5); 6 weeks, 2.1 ± 1.01 (range, 4.5–0); 12 weeks, 1.59 ± 1.03 (range, 4.5–0); 6 months, 1.70 ± 1.51 (range, 6.0–0); and 12 months, 1.8 ± 1.9 (range, 7.0–0).

The mean VAS score for leg pain was as follows: preoperative, 7.29 ± 0.78 (range, 8.5–6.0); postoperative,
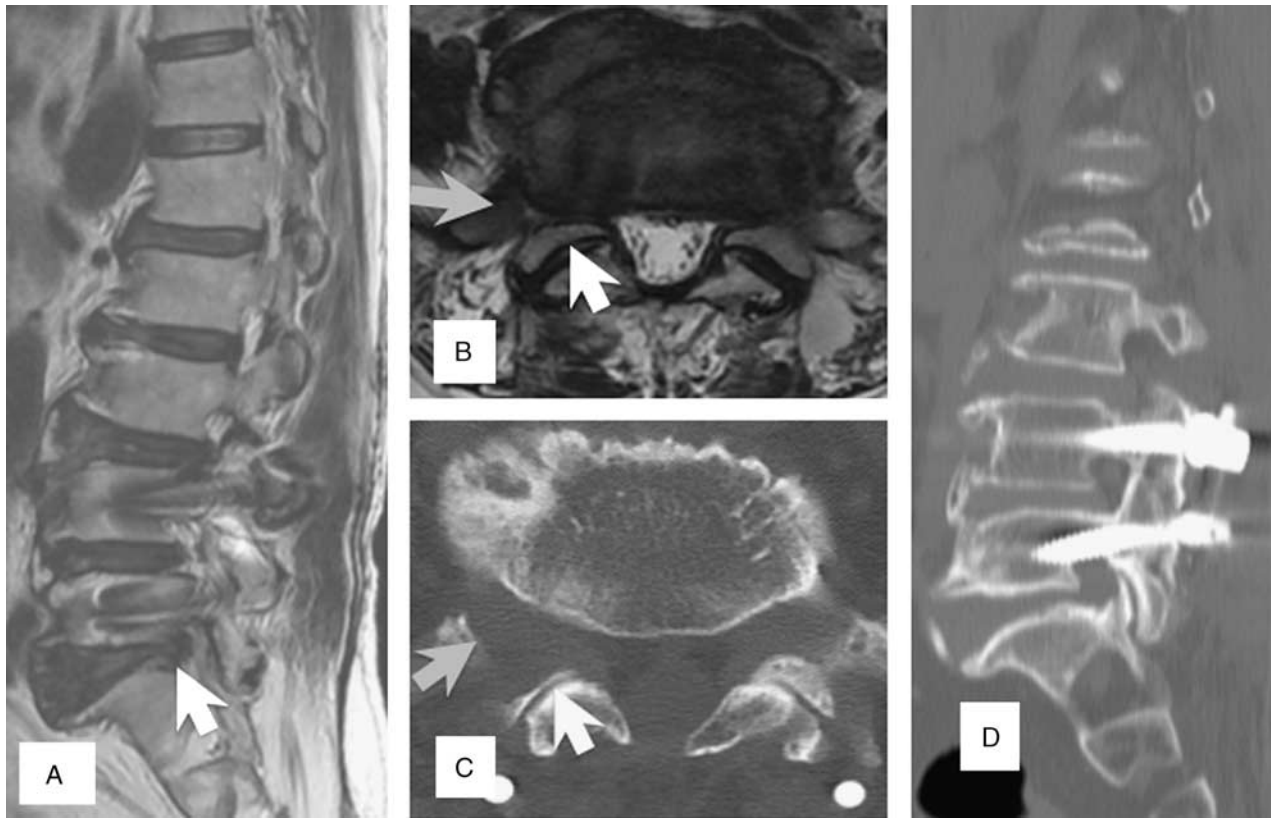
FIGURE 7. A and B, Preoperative magnetic resonance imaging showing disk bulging and a hypertrophic facet joint leading to right foraminal stenosis (white arrows) and extraforaminal stenosis (gray arrow) in a 72-year-old woman with a history of L4–5 spinal fusion and new L5 radiculopathy. C and D, Postoperative computed tomography showing the trumpet shape of the foramen (white arrow) and extra-foramen (gray arrow) after decompression by both trephine and endoscopic burrs.

2.97 ± 0.47 (range, 3.5–2); 6 weeks, 2.27 ± 0.75 (range, 3.5–1); 12 weeks, 1.38 ± 1.53 (range, 4.5–0); 6 months, 1.05 ± 1.5 (range, 4.5–0); and 12 months, 1.41 ± 1.2 (range, 8.0–0; Fig. 8).

The mean Oswestry Disability Index was 61.53% (range, 83%–50%) immediately preoperatively, 19.9% (range,

0%–37%) at 6 weeks, 11.5% (range, 0%–24%) at 6 months, and 15.8% (range, 0%–83%) at 1 year postoperatively.

Reoperation

Two patients with earlier L2–L5 fusion underwent revisional surgery 1 year after the surgery, 1 underwent TLIF,
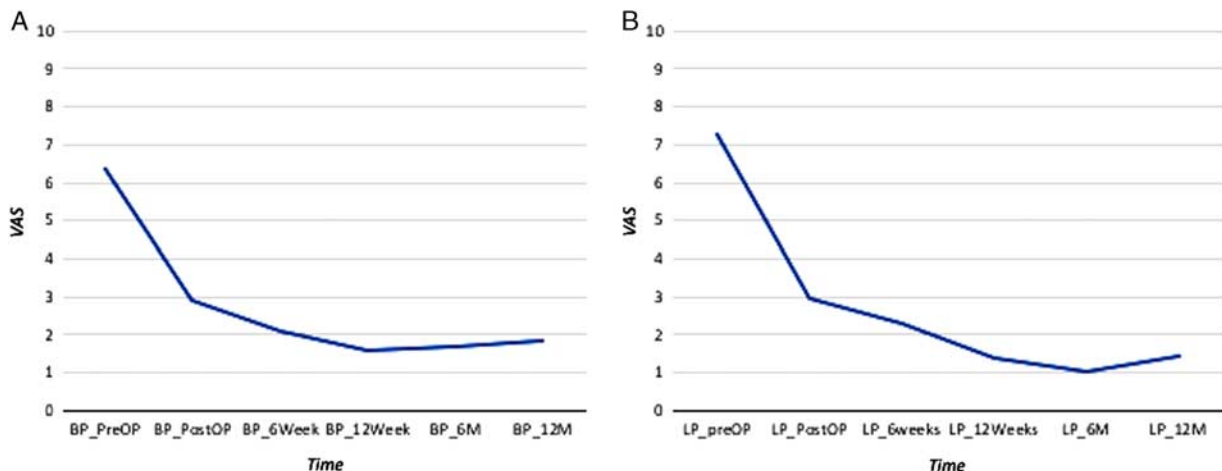

FIGURE 8. Leg pain (A) and back pain (B) before and after surgery.

and 1 other patient underwent revisional FETD secondary for recurrent leg pain.

DISCUSSION

Lumbar FS pathology was first reported in 1927 and was defined as lateral lumbar stenosis.[4,5] Lumbosacral FS has some special anatomical features, such as the L5 root having the largest root diameter among all lumbar roots, and a large portion of the L5 dorsal root ganglion being frequently located just over the L5–S1 foramina.[6,7] Because of these special anatomic features of the L5–S1 region, lumbosacral FS accounts for 75% of all FS, making it the most common location for FS.[8] The pathologies leading to L5 neuropathy in the extraspinal cannel area can be not only FS but also EFS. L5–S1 FS and EFS have been described in detail and include a hypertrophic facet joint with posterolateral osteophyte,[3] a bulging annulus fibrosus, a hypertrophic ligamentum flavum, and sometimes osteophytes over the outer region such as the lumbosacral transitional vertebra.[9,10] FS and EFS with exiting root entrapment may account for 8%–11% of all cases of lumbar stenosis that require surgical intervention.[11,12]

FS diagnosis through image studies is difficult. Kunogi and Hasue[12] successfully treated 26 patients with FS. They used myelography as the diagnostic tool. Only 12 patients had positive radiologic findings. MRI is the most sensitive tool for detecting spinal stenosis in current clinical practice. However, extraforaminal entrapment of the L5 nerve root in the lumbosacral tunnel leading to L5 radiculopathy can be missed on conventional MRI.[13–16] Moreover, L5 FS diagnosis can be difficult. FS is graded in MRI by using a classification system reported by Lee et al,[17] but the L5–S1 foraminal size can be sensitive to weight-bearing or postural changes.[3] Therefore, L5–S1 stenosis may seem as low grade on MRI when the classification of Lee and colleagues is used.

Preoperatively confirming the diagnosis of FS and EFS is thus difficult and dependent on the combination of clinical data (clinical presentation, history, and physical examination findings, ie, positive Kemp's sign) and radiologic findings in computed tomography, myelography, or MRI. Complete exposure and examination of the L5 root from the foramen to the distant area during surgery is crucial to achieve sufficient decompression. On the basis of our findings, this ameliorated FETD technique can be used to treat L5–S1 FS or EFS and can achieve favorable short-term clinical outcomes.

Several methods have been described for treating L5–S1 FS. Transforaminal decompression and interbody fusion are reliable surgical procedures for treating the condition, but complications such as nonunion and adjacent disease can occur.[18] Less invasive procedures such as decompression prevent the occurrence of fusion disease and are becoming more popular, especially for patients with multiple comorbidities.

Microsurgical decompression of far lateral or foraminal lesions using a paraspinal approach was introduced by Wiltse and Spencer.[19] Al-Khawaja et al[20] concluded that decompression of far lateral lesions through the Wiltse approach is a safe and effective procedure. However, none of the lesions were at the L5–S1 level in their series. Chang et al[21] reported that 21.7% of patients had persistent or recurrent leg pain after decompression. Bae et al[22] reported a high percentage of fair and poor outcomes (41.9%) in their series in which they used the Wiltse approach to decompress FS lesions. Most of those failures occurred at the L5–S1 level. The authors concluded that the poor outcomes were caused by large areas of facet resection and annular excision, which could have led to segmental instability, specifically at the L5–S1 level. Choi et al[23] reported that 33% of patients experienced persistent or recurrent pain after decompression of L5–S1 FS.

We believe that the special anatomic features of the relatively narrow operative field between the facet joints and sacral ala make decompression difficult when attempting to preserve most of the facet joints by using traditional microsurgical techniques.

Doi et al[24] reported the successful use of an endoscopic system in treating 17 patients with FS and EFS. They performed their operations under general anesthesia and used 1.6-cm-diameter tubular retractors. Furthermore, they concluded that FS and EFS were difficult to diagnose solely using objective diagnostic tools such as MRI and CT. Koga[25] reported decompression of lumbar FS at L5–S1 by using a percutaneous endoscopic translaminar approach under general anesthesia. The translaminar approach is adequate for use in the case of hidden nerve entrapment; however, its use may be limited in cases of far lateral nerve root entrapment. We believe that it would be difficult to correctly distinguish between FS and EFS before surgery in some cases. Matsumoto et al[15] reported L5 entrapment in the outer region and compression of L5 by the sacral ala, which can be missed before surgery.

During FETD, with the endoscopy instrument moving horizontally through the widened extraforaminal space, the foramen can be completely decompressed and examined, and moving the endoscope vertically, from a 45 degree to an 80 degree position toward the outer region, can facilitate access to pathologies including bulging lateral disks and the sacral ala.

Choi et al[26] successfully treated FS in the lumbosacral region through biportal arthroscopic spine surgery. They reported complications such as muscular edema, hydroperitoneum, incomplete decompression, blurred surgical view, and injury to the radicular artery in their learning curve because of unfamiliarity with the anatomy, especially when the patient was under general anesthesia.

FETD for spinal stenosis has undergone rapid development recently. Lubbers et al[27] reported using percutaneous endoscopy for L5–S1 far lateral disk herniation under general anesthesia. They reported shorter operative times and favorable clinical outcomes. In our study, many patients had hypertrophic facets and ligamentum flava leading to FS. Notably, prolonged operative times were required to perform unroofing for clearer visualization of the L5 root in the foraminal space.

FETD for FS performed under local anesthesia was introduced by Ahn et al.[1] They reported favorable results with endoscopic foraminoplasty to treat FS. Eleven of their patients had disease at the L5–S1 level. However, according to Yang, with far lateral stenosis caused by hypertrophic sacral ala at the L5–S1 level, adequate removal of the sacral ala and the FETD technique remain challenging. The main difference of the technique described in this study from Dr Ahns technique is inferior fenestration of medial L5 transverse process. This procedure allowed for a wider field when viewed under the endoscope, especially in patients with a high iliac crest. We believe that by using a vertical trajectory, the working cannula can make evaluation of the L5 roots traveling toward extremely far lateral regions easier.

Performing FETD for L5–S1 FS or EFS decompression has several advantages. First, the 8-mm-diameter working channel can reach target lesions smoothly, even under local anesthesia. This is essential for patients with multiple comorbidities and high general anesthesia risks. In addition, the morphology of the dorsal root ganglion can easily be confused for tendinous or muscular structures. Stretching of the soft tissue can exacerbate radicular symptoms and confirm the identification of the nerve root structure. This could be a safe way of protecting the exiting nerve root from injury. Second, limited destruction of the S1 facet, which is essential for segmental stability, and inferior fenestration of the L5 transverse process may enable adequate visualization along the L5 nerve root in the interforaminal space through the 30 degree endoscopic system. Third, a cranially bulging disk and the annulus fibrosus can be removed without massive destruction of the pars interarticularis. Damage to the pars interarticularis can lead to segmental instability and nerve compression sequelae. Maintaining stability when most of the bony structures are retained is critical.

This procedure also has some disadvantages. First, the surgeon must be familiar with the intraforaminal structures. Initial surgeries performed by a surgeon new to the procedure may be prolonged because of the learning curve. The patient could face discomfort when lying in the prone position for a long period. Second, in some cases, the L5 nerve root should be retracted by rotating and pushing the bevel-ended cannula during the disk removal process. In patients with anxiety, this could be challenging because it may cause intraoperative radicular symptoms. Some authors have recommended the monitoring of patients by using electromyography when FETD is performed under general anesthesia to prevent nerve injury.[28] This could be an alternative to local anesthesia.

The most crucial aspect of the procedure is identification of the L5 exiting nerve root after initial unroofing. This enables the surgeon to identify a safe working zone at the beginning of the endoscopy. Complete removal of the lateral facet, partial removal of the inferior-medial L5 transverse process, and the underlying ligamentum flavum promote full exposure of the exiting root from its proximal exit point to the extraforaminal region and facilitate complete decompression.

After the 1-year follow-up, 2 patients received revisional surgery. Both patients previously had long fusion from L2 to L5 and had a high BMI of 30 and 32 kg/m^2, respectively. Hashimoto et al[29] reported high BMI and long fusion as critical risk factors for adjacent disease. We believe that the reason for recurrent radiculopathy in these 2 patients was high biomechanical stress on L5–S1. The long-term outcomes of these types of case should be analyzed.

Limitations of This Study

This study had several limitations. We had to rely on patient histories, physical examinations, and selective nerve block tests, because no definitive objective diagnostic tool is yet available for L5–S1 EFS and FS. Second, there was no comparative group, the clinical outcome of this method cannot be compared with other methods such as traditional microscopic decompression. In addition, the number of patients was small, and the follow-up duration was short. The long-term results of FETD for L5–S1 FS and EFS remain unclear, especially among patients with a history of fusion at levels above L5.

CONCLUSION

L5–S1 FS and EFS are frequently overlooked on MRI, which can lead to L5 radiculopathy from degenerative disease, with or without far lateral disk herniation of L5–S1. FETD for FS is well developed, and excellent results have been reported. The unique anatomic features of L5–S1 make diagnosis and treatment of FS and EFS in that location difficult. However, we believe that with adequate understanding of the related anatomies and careful preoperative planning, including inferior fenestration of medial L5 transverse process and recognition of the lumbosacral tunnel, FETD can be used to successfully treat FS and EFS of L5–S1 with favorable short-term results.

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