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Original Article

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Reducing Postoperative Neurological Complications in Uniportal Full-Endoscopic Lumbar Interbody Fusion: Efficacy of the GUARD Technique Combined With Delayed Ligamentum Flavectomy

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Objective: Uniportal full-endoscopic transforaminal lumbar interbody fusion (FE-TLIF) carries a unique risk of nerve traction and abrasion injury during cage insertion. This study aims to evaluate the clinical efficacy of the GUARD technique and delayed ligamentum flavectomy in reducing postoperative radicular pain and neurapraxia in patients undergoing uniportal FE-TLIF.
Methods: A retrospective analysis was conducted on 45 patients with an average age of 53.9 ± 12.4 years who underwent either FE facet-sparing TLIF (FE fs-TLIF) or FE facet-resecting TLIF (FE fr-TLIF). Patients were divided into 2 groups: the sentinel group (21 patients) using traditional sentinel pin techniques, and the GUARD group (24 patients) using the GUARD technique with delayed ligamentum flavectomy. Patient-reported outcomes included the visual analogue scale (VAS) for leg and back pain, and Oswestry Disability Index. Complication rates, including incidental durotomy, postoperative neurapraxia, and hematoma, were also documented.
Results: Postoperative radicular pain in the legs was significantly reduced at 6 weeks in the GUARD group compared to the sentinel group (VAS: 2.201 vs. 3.267, p = 0.021). The incidence of postoperative neurapraxia was markedly lower in the GUARD group (0% vs. 19%, p = 0.047). Both groups showed similar improvements in disc height, segmental lordosis, and lumbar lordosis at the 1-year follow-up, with no significant differences in endplate injury or fusion rates.
Conclusion: The GUARD technique and delayed ligamentum flavectomy significantly enhance patient safety by reducing postoperative radicular pain and neurapraxia without incurring additional costs. These techniques are easy to learn and integrate into existing surgical workflows, offering a valuable improvement for surgeons performing FE-TLIF procedures.

Keywords: Lumbar spine, Endoscope, Interbody fusion, Neurapraxia, Cage glider, Ligamentum flavum

INTRODUCTION

Endoscopic lumbar interbody fusion surgery has gained popularity in recent years for treating lumbar degenerative diseases due to its advantages, which include superior short-term clinical outcomes, faster postoperative recovery, decreased bleeding, shorter hospital stays, and reduced muscle retraction.[1-3] The procedure has evolved to include facet-sparing and facet-resecting approaches, namely full-endoscopic facet-sparing transforaminal lumbar interbody fusion (FE fs-TLIF) and full-endoscopic facet-resecting transforaminal lumbar interbody fusion (FE fr-TLIF).[4-6] In FE fs-TLIF, also known as trans-Kambin lumbar interbody fusion, the working channel is introduced into the disc space via the Kambin triangle after limited foraminoplasty at the ventral superior articular process (SAP).[5] Conversely, the FE fr-TLIF, or posterolateral approach, involves resection of the ipsilateral superior and inferior articular processes (IAPs) to create an extended Kambin triangle for safe insertion of the bone graft and cage.[7] Both FE-TLIF procedures can be performed using uniportal or biportal endoscopic approaches.[3,7-9]

Despite the benefits of these minimally invasive techniques, postoperative dysesthesia remains the most frequent complication, affecting 1%–23% of FE-TLIF surgeries.[3,10-12] Incidental durotomy, another significant complication, can occur in both uniportal and biportal FE-TLIF, frequently due to instrumental injuries.[11,13-16] These complications are particularly risky during cage insertion in uniportal FE-TLIF, as it is conducted entirely under fluoroscopic guidance without direct endoscopic visualization.[13] Although various endoscopic dural repair techniques have been described,[17-19] effective preventive strategies for incidental durotomy are still lacking.[14,20] Cage gliders were introduced to shield neural elements from surgical instruments; however, they have not entirely eliminated postoperative dysesthesia.[4,21] In some cases, improper positioning of the cage glider has even resulted in injury to the exiting nerve root instead of providing protection.[22,23]

To enhance the protection of neural elements during uniportal FE-TLIF, we developed a new cage glider insertion technique called the "GUARD" technique and optimized the workflow by delaying ligamentum flavectomy until after the lumbar interbody fusion was completed. This study is a retrospective analysis of 2 cohorts, comparing outcomes before and after the implementation of the GUARD technique in conjunction with delayed ligamentum flavectomy. We hypothesized that these protective measures could reduce neurological complications and facilitate postoperative functional recovery.

MATERIALS AND METHODS

1. Population

This retrospective analysis included patients who underwent uniportal FE fs-TLIF and FE fr-TLIF for lumbar degenerative disease between January 2020 and December 2022. All procedures were performed by a single experienced spine surgeon at a single tertiary medical center, utilizing full-endoscopic techniques with an endoscopic spine system (Vantage Biotech Co., Ltd., Taoyuan, Taiwan).

The study included all consecutive patients who met the following criteria: (1) persistent low back pain and radiating pain in the lower extremities despite 3 months of conservative treatment; (2) radiographic evidence of spinal stenosis (central or foraminal), unstable spondylolisthesis (degenerative or spondylolytic), or advanced degenerative disc disease; and (3) follow-up duration exceeding one year. Patients were excluded if they had (1) a history of fusion surgery at adjacent spinal levels, (2) simultaneous lumbar spinal surgeries (discectomy or decompression) at different levels, (3) prior spine infection, or (4) malignant or metastatic lesions of the spine.

2. Preoperative Evaluation

The surgical level of canal stenosis was determined based on clinical symptoms and imaging findings. Routine plain radiography of the lumbar spine, including anteroposterior views and dynamic flexion and extension lateral views, was conducted to assess spinal instability and disc height. Magnetic resonance imaging of the lumbar spine was used to grade stenosis according to the Schizas classification. This study was approved by the Institutional Review Board (authorization number: A-ER-110-001), and informed consent was obtained from all enrolled patients following a thorough discussion of the operative methods, alternatives, benefits, anesthetic methods, and postoperative programs.

3. Author's Preference for Surgical Approach

The choice between uniportal FE fs-TLIF and FE fr-TLIF primarily depends on the individual patient's condition and preoperative imaging. Patients with hypertrophied facet joints, facet cysts, or ligamentum flavum pathology are typically prioritized for FE fr-TLIF, which allows direct decompression by removing the ipsilateral facet joint and ligamentum flavum. Correction of sagittal alignment is another consideration, as the larger cage used in FE fr-TLIF, due to the wider surgical corridor, has the potential to better improve sagittal parameters.

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FE fs-TLIF is generally less suitable for patients with central stenosis classified as Schizas grade D with bilateral radicular symptoms or neurological claudication, who typically require direct bilateral decompression. It is also less appropriate for patients who have undergone transforaminal endoscopic lumbar discectomy or those with severely collapsed disc spaces. Conversely, FE fr-TLIF is less appropriate for patients who have had previous interlaminar endoscopic or open decompression.

4. Full-Endoscopic Lumbar Interbody Fusion

1) Surgical approaches

Under general anesthesia, the patient is positioned prone on the Wilson frame. Following sterile preparation, guidewires for percutaneous pedicle screws are placed under fluoroscopic guidance. Typically, we delay the insertion of screws and rods until after the lumbar interbody fusion to provide ample space for endoscopic manipulation. However, in cases of severely collapsed disc spaces, contralateral screws and rods are placed prior to the lumbar interbody fusion to facilitate disc space distraction. The insertion of ipsilateral screws and rods is postponed as long as possible to prevent interference with the endoscopic procedures and to avoid interferences during fluoroscopic examinations.

A 2-cm skin incision is made to create a portal for the spine endoscope system. In FE fr-TLIF, this incision is typically on the lateral border of the cranial vertebral pedicle at the target level, often utilizing the same incision made for pedicle screw placement. For FE fs-TLIF, the incision is positioned 40–80 mm lateral to the spinal midline, adjusted for individual anatomical variations.

In the FE fs-TLIF approach, the working cannula is positioned over the SAP after accessing the muscle plane between the longissimus and iliocostalis muscles at the target spinal segment. Facet capsule release is performed to facilitate the reduction of spondylolisthesis and disc height restoration. The ventral aspect of the SAP is resected using endoscopic high-speed burrs until the junction with the pedicle, completing the foraminoplasty. Sequential dilatation is performed to gain access to the extended Kambin triangle and the intervertebral disc. The working cannula is then advanced into Kambin's triangle to facilitate discectomy and endplate preparation.

In the FE fr-TLIF approach, the working cannula is docked on the pars interarticularis of the upper vertebra. Under endoscopic visualization, the medial and lateral margins of the IAP are exposed. The ipsilateral IAP is resected, either from the spinolaminar junction to the superolateral region using an inside-out technique or from the superolateral region to the spinolaminar junction using an outside-in technique.[4,7] Next, the ipsilateral SAP of the caudal vertebra is resected, extending from the junction of the SAP and the superior lamina of the inferior vertebra to the junction of the SAP and the transverse process. Ipsilateral total facetectomy and laminotomy are completed using endoscopic drills, punches, and osteotomes. The resected bone is used as fusion material during the subsequent interbody fusion procedure. After bony resection, the lateral margin of the ligamentum flavum is spontaneously detached and becomes floating. At this stage, the ligamentum flavum is preserved to act as a protective layer between the instruments and neural elements during the following procedures.

2) Protection of neural elements during endoscopic interbody fusion: guard technique

After adequately exposing the intervertebral disc space, an annulotomy is performed using an endoscopic knife and punches. An obturator is then slid through the annulotomy into the disc space via the working channel under endoscopic visualization. To prevent nerve root injury during endplate preparation and cage insertion, we developed the glider used as a rotary device (GUARD) technique.[24] This technique establishes a secure quadrangular space, facilitates discectomy and endplate preparation, and prevents neural damage during cage insertion (Fig. 1).

For FE fs-TLIF procedures, where the exiting nerve root is at risk, a single-tipped cage glider (single-tipped expandable cage glider, Vantage Tech Co. Ltd.) is used. The glider's tip is oriented caudally and rotated 135° after insertion into the intradiscal space, depending on the side of the operation: clockwise for left-side surgery and counterclockwise for right-side surgery. The bevel of the glider acts as a shield over the inferomedial margin of the exiting nerve.

In FE fr-TLIF procedures, where the protective bony structure is absent after facetectomy, a double-tipped cage glider (double-tipped spring-loaded cage glider, Vantage Tech Co. Ltd.) is used. Initially oriented cranial-caudally, the glider is rotated 90° after insertion to protect both the traversing and exiting nerve roots during endplate preparation and cage insertion. Additionally, the double tips offer the advantage of countering forces against each other, which allows for more stable and controlled expansion of the cage. This reduces the risk of the glider being displaced or deviated, ensuring more precise cage placement (Fig. 2).

Prior to the development of the GUARD technique, the exiting nerve root was protected using the sentinel pin technique.

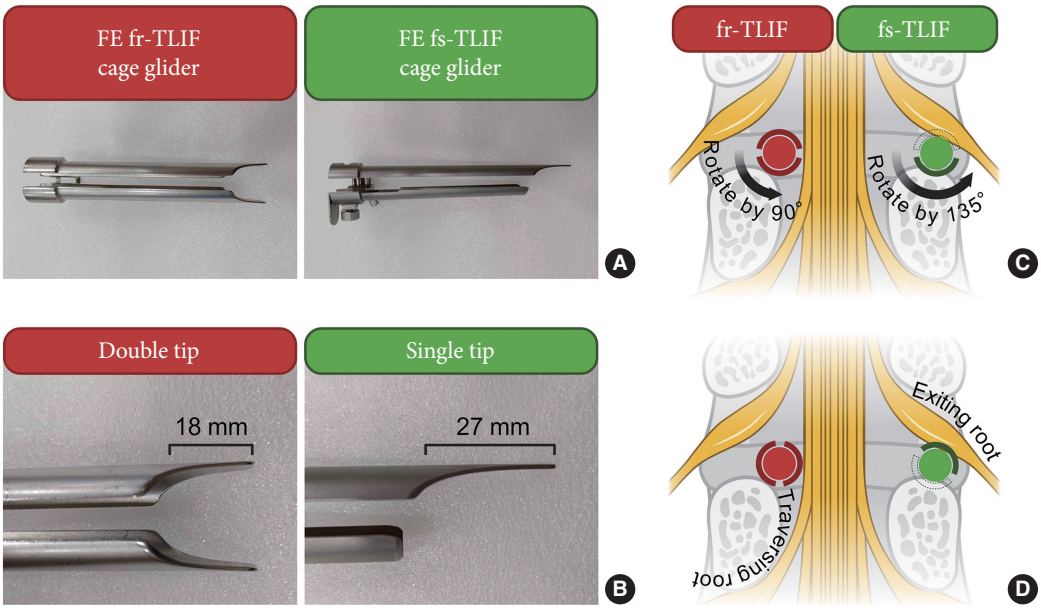

Fig. 1. The cage gliders and the GUARD technique. (A) The respective cage gliders for FE fr-TLIF and FE fs-TLIF. (B) Illustration of the double-tip glider used for FE fr-TLIF, featuring 2 18-mm blades that shield the traversing and exiting nerve roots from surgical instruments. It also shows the single-tip glider used for FE fs-TLIF, with a 27-mm blade designed to shield the exiting nerve root. (C) Demonstration of the first step of the GUARD technique. Initially, the blades are oriented cranio-caudally when inserted. In FE fr-TLIF, a 90° rotation is recommended to shield the traversing nerve root, whereas in FE fs-TLIF, a 135° rotation is recommended to protect the exiting nerve root. (D) Safe and successful shielding of the nerve roots. GUARD, glider used as a rotary device; FE fr-TLIF, full-endoscopic facet-resecting transforaminal lumbar interbody fusion; fs-TLIF, full-endoscopic facet-sparing transforaminal lumbar interbody fusion.

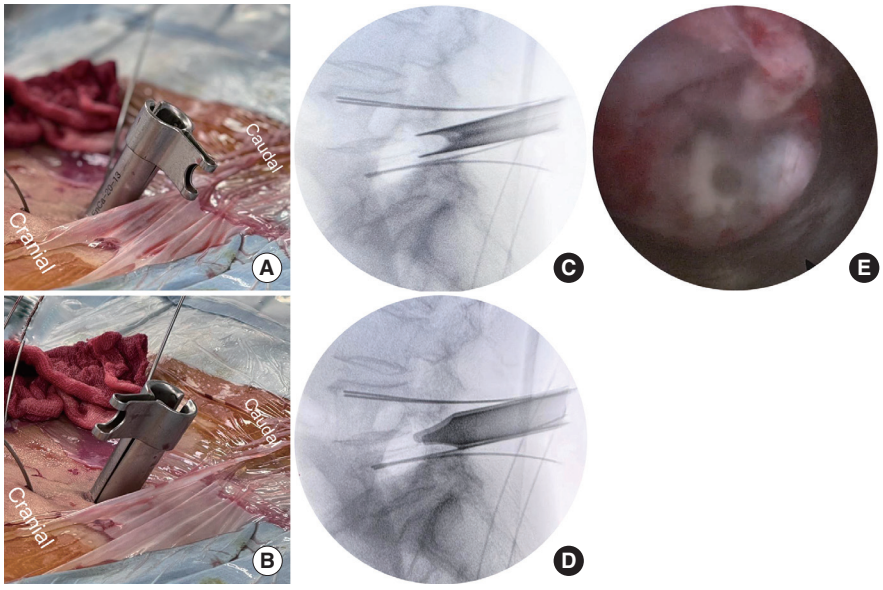

Fig. 2. Application of GUARD technique in endoscopic lumbar interbody fusion. (A and C) Display the gross and fluoroscopic images of the double-tip cage glider with the tips oriented craniocaudally during a FE fr-TLIF procedure. (B and D) Show the images after a 90° rotation of the double-tip cage glider, ensuring proper shielding of the traversing nerve root. (E) Presents the endoscopic view following the completion of a FE fr-TLIF, where the traversing nerve root is immediately adjacent to the cage entry site. GUARD, glider used as a rotary device; FE fr-TLIF, full-endoscopic facet-resecting transforaminal lumbar interbody fusion; fs-TLIF, full-endoscopic facet-sparing transforaminal lumbar interbody fusion.

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This method involved freeing the nerve root from adhesions with a blunt dissector, mobilizing it to a safe position with a retractor, and inserting a K-wire under endoscopy to extend Kambin's triangle into a secure quadrangular space for disc preparation and cage insertion.

3) Endoscopic lumbar interbody fusion

Once a secure quadrangular space is established, the cartilaginous endplate is removed using an endoscopic drill or curved dissectors, and extracted with forceps through the cage glider. Curettes or shavers are used sparingly during endplate preparation to avoid injury to the bony endplate. Trial cages of serial sizes are inserted into the disc space to determine the appropriate cage size. After disc and endplate preparation, autogenous bone graft from the previously resected bone, demineralized bone matrix, and synthetic bone graft substitute material are impacted into the disc space with a bone graft delivery funnel. The final cage, a straight bullet-type polyetheretherketone cage, is inserted obliquely into the disc space under fluoroscopic guidance, aiming to cross the midline, and is adjusted using impactors. This cage insertion process is performed under fluoroscopic guidance because, at this stage, the working channel in the uniportal endoscope system is completely occupied by the cage and impactor, making endoscopic visualization unavailable.

4) Endoscopic decompression with removal of ligamentum flavum

After completing the lumbar interbody fusion procedure, the cage glider is withdrawn, and the working channel is repositioned into the epidural space for decompression. If bilateral decompression is needed, contralateral laminectomy and decompression are performed using an over-the-top technique. The labile ligamentum flavum is then removed at this stage. Once complete ligamentum flavectomy and adequate decompression are achieved, meticulous hemostasis is performed using a bipolar cautery system and a gelatin-thrombin hemostatic matrix. Following this, the endoscope is withdrawn, and a closed drainage tube is inserted. The surgery is finalized with percutaneous pedicle screw and rod fixation.

5. Assessment of Radiological Outcome

Radiography and computed tomography (CT) were used peoperatively, immediately postoperatively, and at 1 year postoperatively to assess fusion, subsidence, and lordosis. Radiological parameters were measured by 2 independent surgeons who did not participate in the surgery.

The disc height at the index level was calculated by averaging the heights at the anterior, middle, and posterior intervertebral disc. Lumbar lordosis was measured as the angle between the superior endplate of L1 and the inferior endplate of L5, while segmental lordosis was defined as the angle between the superior endplate of the upper vertebra and the inferior endplate of the lower vertebra at the index level. Cage position was assessed from the axial CT scan. If 25%–50% of the cage crossed the midline, it was classified as crossing; otherwise, it was classified as unilateral.[13]

Subsidence was assessed on standing lateral radiographs by comparing disc height immediately postoperatively and at one year postoperatively. Subsidence was graded as follows: grade 0: 0%–24% loss of postoperative disc height; grade I: 25%–49% collapse; grade II: 50%–74% collapse; grade III: 75%–100% collapse. Endplate injury was determined from the immediate postoperative radiographs and defined as vertebral body collapse of more than 25% of the cage height due to bony endplate breakage.

Bone fusion was evaluated using CT scan at 1 year postoperatively, based on the Bridwell fusion grading system: grade I, fused with trabecular bone formation; grade II, graft intact, not fully remodeled and incorporated, but no lucency present; grade III, graft intact with potential lucency present at the top and bottom of the graft; grade IV, fusion absent with collapse/resorption of the graft. The fusion rate was calculated by summing the cases classified as grades I and II.[25]

6. Clinical Outcome Assessment

To examine functional recovery over time, a general linear model for repeated-measurement analysis of variance was employed. Participants were considered as a random factor, with measurements taken immediately preoperative, and at 1.5, 3, 6, and 12 months postoperative. The evaluation modalities included the visual analogue scale (VAS) scores for back and leg pain, the Oswestry Disability Index (ODI), and the physical function domain of Short Form-36 (SF-36-PF) Health Survey Questionnaire.

The cohort was dichotomized according to the technique used to protect the nerve root. Differences in trends between subgroups over the year were assessed using between-subject effects. The Mann-Whitney U-test was employed to compare functional scores at specific time points. Comparisons of preoperative and postoperative results were performed using the generalized estimating equation method with IBM SPSS Statistics ver. 21.0 (IBM Co., Armonk, NY, USA).

RESULTS

1. Patient Demographics

The study involved 45 patients (15 men, 30 women) with an average age of 53.9 ± 12.4 years, who underwent either FE fs-TLIF or FE fr-TLIF. A total of 54 lumbar levels were treated, most commonly at the L4–5 level (61.1%). Degenerative and spondylolytic spondylolistheses were the predominant condition treated (88.9%).

Among the initial 21 patients with 26 operative levels, whose nerve roots were protected using the sentinel pin technique, 10 underwent FE fs-TLIF and 11 underwent FE fr-TLIF. These patients constituted the "sentinel group." For the subsequent 24 patients with 28 operative levels, who had their nerve roots protected using the GUARD technique, 14 underwent FE fs-TLIF and 10 underwent FE fr-TLIF. They were classified as the "GUARD group." There was no significant difference in the severity of stenosis or diagnosis between the 2 groups (Table 1).

Table 1. Patient demographics

Variable	Total	Sentinel	GUARD
Age (yr)	53.9 ± 12.4	53.9 ± 10.6	53.9 ± 14.0
Sex, male:female	15:30	5:16	10:14
Segment			
L1–2	2	2 (3.7)	0 (0)
L2–3	2	1 (1.9)	1 (1.9)
L3–4	6	2 (3.7)	4 (7.4)
L4–5	33	19 (35.2)	14 (25.9)
L5–S1	11	2 (3.7)	9 (16.7)
Diagnosis			
Spondylolytic spondylolisthesis	14	7 (15.6)	7 (15.6)
Degenerative spondylolisthesis	26	12 (26.7)	14 (31.1)
Recurrent disc herniation	5	2 (4.4)	33 (6.7)
Schizas classification			
B	5	3 (5.6)	2 (3.7)
C	36	18 (33.3)	18 (33.3)
D	13	5 (9.3)	8 (14.8)
Approach			
FE fs-TLIF	24	10 (22.2)	14 (31.1)
FE fr-TLIF	21	11 (24.4)	10 (22.2)

Values are presented as mean ± standard deviation or number.
Sentinel, sentinel pin technique; GUARD, "Glider Used As a Rotary Device" protection technique; FE fs-TLIF, full-endoscopic facet-sparing TLIF; FE fr-TLIF, full-endoscopic facet-resecting TLIF.

2. Radiological Outcomes

Following FE-TLIF, both the sentinel and GUARD groups showed restored disc height, segmental lordosis, and lumbar lordosis, with no statistically significant difference between the groups throughout the 1-year postoperative follow-up. The cage sizes used were similar between the groups ($p = 0.406$). The cage crossed the midline in 68.5% of the cases, with no significant difference between the groups (61.5% in the sentinel group vs. 75% in the GUARD group, $p = 0.287$).

The overall endplate injury and subsidence rate was 9.3%,

Table 2. Radiological outcomes of endoscopic lumbar interbody fusion

Variable	Total	Sentinel	GUARD	p-value
Disc height				
Preoperative	6.26 ± 1.41	6.44 ± 1.59	6.10 ± 1.22	0.376
Immediately postoperative	9.94 ± 0.82	9.94 ± 0.93	9.94 ± 0.71	0.986
1 Year postoperative	8.99 ± 1.04	9.02 ± 1.11	8.96 ± 1.00	0.846
Segmental lordosis				
Preoperative	12.52 ± 4.97	12.50 ± 5.44	12.54 ± 4.59	0.979
1 Year postoperative	15.31 ± 5.39	16.17 ± 6.04	14.58 ± 4.70	0.308
Lumbar lordosis				
Preoperative	19.60 ± 5.99	19.91 ± 6.63	19.30 ± 5.43	0.712
1 Year postoperative	25.56 ± 5.68	26.47 ± 6.50	24.90 ± 4.66	0.402
Cage size				0.406
8:9:10:11	5:22:19:8	2:9:9:6	3:13:10:2	
Cage position				0.287
Unilateral	17 (31.5)	10 (38.5)	7 (25.0)	
Crossing	37 (68.5)	16 (61.5)	21 (75.0)	
Endplate injury	5/54 (9.3)	3/26 (11.5)	2/28 (7.1)	0.639
Subsidence rate				
0:1:2:3	49:5:0:0	23:3:0:0	26:2:0:0	0.639
Bridwell fusion grading system (at 12 mo)				0.868
Grade 1	41 (75.9)	20 (76.9)	21 (75.0)	
Grade 2	10 (18.5)	5 (19.2)	5 (17.9)	
Grade 3	3 (5.6)	1 (3.9)	2 (7.1)	
Grade 4	0 (0)	0 (0)	0 (0)	
Fusion rate	51/54 (94.4)	25/26 (96.2)	26/28 (92.9)	0.597

Values are presented as mean ± standard deviation or number (%).
Sentinel, sentinel pin technique; GUARD, "Glider Used As a Rotary Device" protection technique.
The p-values were generated using the Student t-test, chi-square test, or Fisher exact test, as appropriate.

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with no significant difference between the groups (11.5% in the sentinel group vs. 7.1% in the GUARD group, p = 0.639). The overall fusion rate according to the Bridwell fusion grading system (grades 1 and 2) was 94.4%, with no significant difference between the groups (96.2% in the sentinel group vs. 92.9% in the GUARD group, p = 0.639) (Table 2).

3. Functional Outcomes

Over one year postoperatively, the improvement in leg pain was significantly different between the sentinel group and GUARD groups (p = 0.046 by 2-way analysis of variance [ANOVA]). At 6 weeks, *post hoc* analysis revealed significant differences in VAS scores for leg pain (3.267 vs. 2.201, p = 0.021 by Mann-Whitney U-test), though this was not observed at other time points (Fig. 3A). In contrast, there was no significant difference in back pain recovery (p = 0.065). Other patient-reported outcomes measurements, including ODI and SF-36-PF scores, showed no significant differences between the groups (p = 0.710 and p = 0.302 by 2-way ANOVA, respectively) (Fig. 3B–D).

4. Complications and Management

We discovered 7 cases of postoperative complications (Supplementary Table 1).

Incidental dural tear occurred in one patient from the sentinel group and none from the GUARD group, with no significant difference between the groups (p = 0.482 by Fisher exact test). The tear happened during delayed ligamentum flavectomy for the decompression of central stenosis, well after completion of the interbody fusion. After the dura was accidentally perforated by the Kerrison punch, the Gelfoam strips (Pfizer, Pfuurs, Belgium) were introduced through the endoscopic working sheath into the dura to protect the rootlets and to prevent the herniation of neural elements. The decompression was then finished smoothly and DuraSeal (Integra, Mansfield, MA, USA) adhesives was applied to seal the tear (Fig. 4). Remaining percutaneous instrumentation procedures were completed uneventfully. Postoperatively, the patient was allowed early mobilization after a 24-hour bed rest. The drainage tube was safely removed 72 hours after surgery following a Valsalva maneuver to check for cerebrospinal fluid leakage. The patient did not develop a low-pressure headache or require open dural repair surgery. With the deliberately delayed ligamentum flavectomy strategy, no incidental durotomy occurred during cage introduction of uniportal FE-TLIF.

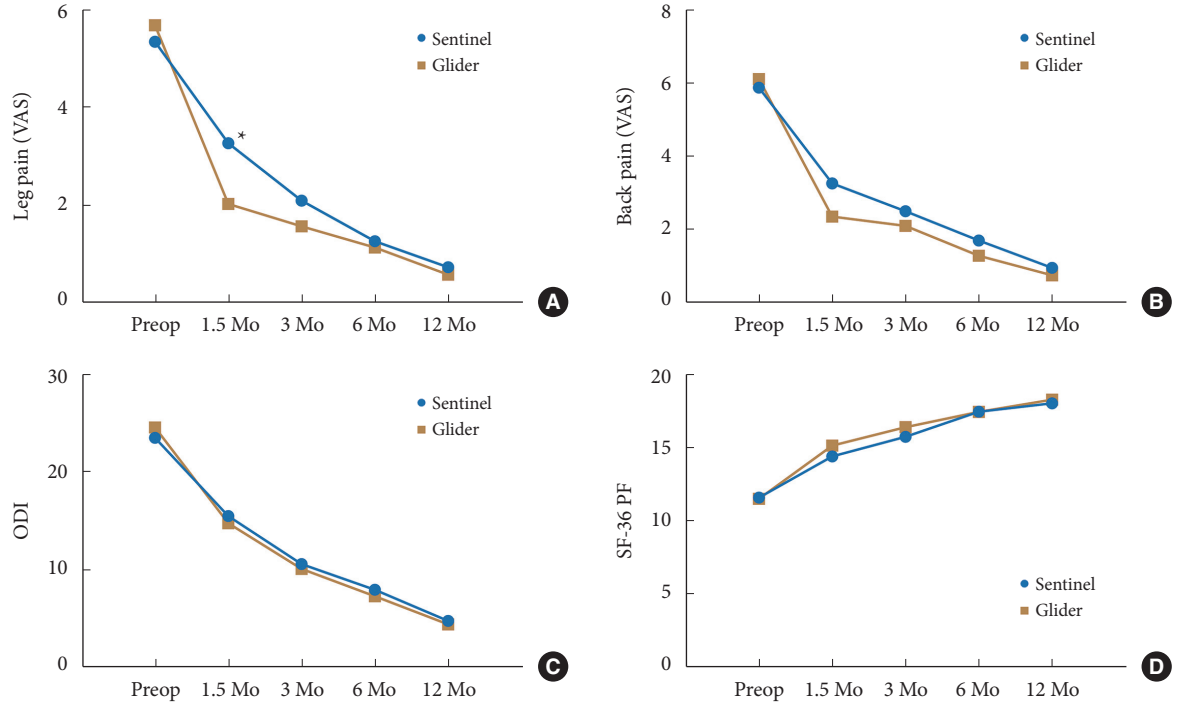

Fig. 3. Functional outcomes of endoscopic lumbar interbody fusion. The line charts illustrate patient-reported outcomes in the sentinel group and the GUARD group over time, including: visual analogue scale (VAS) for leg pain (A), VAS for back pain (B), Oswestry Disability Index (ODI; C), 36-Item Short Form Health Survey (SF-36) physical function (PF) score (D). At 6 weeks, there was a significant difference in the VAS score for leg pain between the groups (3.267 in the sentinel group vs. 2.201 in the GUARD group, p = 0.021 by Mann-Whitney U-test). GUARD, glider used as a rotary device; preop, preoperative.

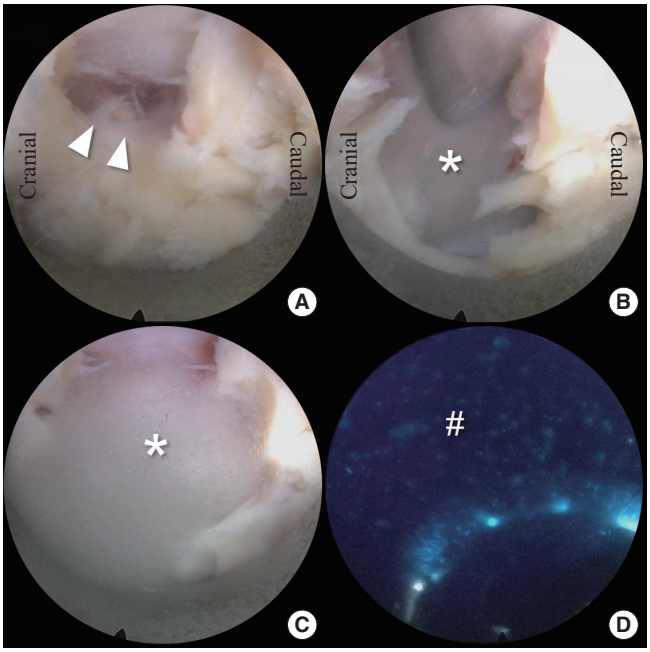

Fig. 4. A case of incidental durotomy. (A) During delayed ligamentum flavectomy after endoscopic lumbar interbody fusion, the dura was incidentally injured by the Kerrison punch. (B) After ensuring that the neural elements did not herniate, the dural defect was temporarily tamponaded with Gelfoam strips. (C) The decompression was then finished smoothly, without further enlargement of the tear. (D) After completing decompression, the surgery was concluded with a watertight closure using DuraSeal (Integra, Mansfield, MA, USA) adhesives. Arrowheads indicate the dural tear, *indicates Gelfoam strips, #indicates DuraSeal agent.

Nerve root injuries occurred in 4 patients from the sentinel group and none from the GUARD group, with this difference being statistically significant ($p = 0.047$ by Fisher exact test). One patient, who underwent a 2-level FE fr-TLIF from L4 to S1, sustained abrasion and traction injuries to the exiting L5 nerve root and the S1 traversing nerve root during cage insertion, resulting in drop foot and neuropathic pain in the anterior third of the plantar foot. This patient required an ankle-foot orthosis, intensive physical therapy, and a combination of imipramine, pregabalin, and celecoxib for 8 months to regain ankle dorsiflexion strength. Additionally, 3 other patients from the sentinel pin group experienced neuropathic pain in the L4 territory after 1-level FE fs-TLIF, necessitating prolonged regular pregabalin and celecoxib for 6 months.

Delayed deep infections were observed in 1 patient from each group, with no significant difference ($p = 0.957$ by chi-square analysis). Both patients underwent secondary open surgery, which included removal of the interbody cage and screws, thorough debridement, and transforaminal interbody fusion with an autologous iliac crest bone graft. Both patients achieved successful lumbar arthrodesis at final follow-up. There were no cases of seizures, epidural hematoma, or aseptic implant loosening requiring secondary surgery.

DISCUSSION

Endoscopic lumbar interbody fusion offers the benefits of minimal dissection and effective endplate preparation. However, uniportal FE-TLIF is technically demanding and carries a unique risk of neural injury during cage insertion. The current study assessed the clinical efficacy of the GUARD technique and delayed ligamentum flavectomy. These strategies significantly reduced postoperative radicular pain in the legs at 6 weeks and markedly reduced the incidence of postoperative neurapraxia. We recommend that surgeons performing FE fr-TLIF and FE fs-TLIF adopt this modified cage glider insertion technique and adjust the workflow by delaying decompression until as late as possible. These techniques enhance the safety of FE-TLIF, reduce complications, and incur no additional costs.

Postoperative dysthesia was the most frequent complication in FE-TLIF surgery. In uniportal FE-TLIF, a distinctive injury pattern is abrasion or traction injury during cage insertion, as this process is guided fluoroscopically without endoscopic visualization.[13,26] Dysthesia occurred in 1% to 9% of FE fs-TLIF cases and was mainly linked to injuries of the exiting nerve root.[11] These injuries often resulted from either direct trauma by surgical instruments or compression by the blade of glider during insertion.[27-29] To address this, Sairyo et al. devised a custom-made single-tip cage glider to shield the exiting nerve root during cage insertion.[21,30] In contrast, postoperative dysthesia occurred in 3% to 23% of FE fr-TLIF, but was primarily associated with traversing nerve root injuries at the lateral recess.[3,10] These injuries often occur due to instrumental damage.[15,31] To shield both the exiting and traversing nerve roots during cage insertion, Kim et al.[4] designed a double-tip cage glider. However, the use of a cage glider did not eliminate postoperative dysesthesia, and some authors reported that it could potentially injure the exiting nerve root if not optimally positioned, possibly causing injury instead of providing protection.[22,23] The GUARD technique in the current study was developed after a patient sustained drop foot, suspected to be correlated with intraoperative abrasion and traction injury of the traversing nerve root during cage insertion without endoscopic visualization. This technique builds on previous works and specifies the exact rotation needed to align the

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glider blades parallel with the nerve root to be protected. The stepped insertion method minimizes the likelihood of the blades injuring the nerve root and enhances the protection of vulnerable neural structures. The GUARD technique has proven to be generalizable and effective in a prior cadaveric anatomical study, without incurring additional costs.[24] The GUARD technique is particularly recommended in cases of severe disc space collapse, where the Kambin triangle is often extremely small. In such scenarios, we prefer a facet-resecting TLIF over a facet-sparing approach, as the former allows for more extensive facet resection and release, facilitating effective disc space distraction. During disc preparation, sequential insertion of trials of increasing size helps to loosen the annulus and longitudinal ligaments. Disc space distraction is then achieved by applying the screw-rod construct contralateral to the symptomatic side. These steps, combined with the GUARD technique, typically enable the safe restoration of disc height and the placement of an appropriately sized cage.

To prevent postoperative dysesthesia, various techniques have been developed to shield the traversing and exiting nerve roots.[1,16,32] However, there is currently no consensus or guideline for managing postoperative pain and palsy. In uniportal FE fr-TLIF, Kim et al.[13] reported that postoperative dysesthesia appeared 3 days after surgery and resolved with conservative treatment. Kuo and Choi[22] and Jiang et al.[33] described cases of neuropraxia caused by cage impingements and direct nerve root retraction injury, which also improved with conservative treatment. Morgenstern et al. treated postoperative dysesthesia with oral pregabalin or selective nerve blocks, reporting complete resolution by an average of 7.2 weeks postoperatively.[6,12] In our practice, we manage postoperative dysesthesia by prescribing gabapentinoids and vitamin B12, adding COX-2 inhibitors if necessary. Gabapentinoids, particularly pregabalin, are preferred due to their significant opioid dose-sparing effects and their ability to prevent the transition from acute to chronic pain after spine surgery.[34-37] Pregabalin is favored over gabapentin for its better efficacy and functional outcomes.[36] We aim to avoid prescribing opioid medications or limit their use to below 50 oral morphine milligram equivalents when necessary to facilitate discontinuation of opioid use by 1 year postoperatively.[35,37]

Incidental durotomy is one of the most precarious complications in endoscopic spine surgery and can occasionally necessitate conversion to open surgery.[11,14,15] Endoscopic dural repair techniques, such as using autologous muscle or fat grafts or commercial collagen fibrin patches like Tachosil (Nycomed, Linz, Austria), have been effectively utilized in both uniportal and biportal endoscopic surgeries.[17-19] These methods are analogous to patch-blocking dura repairs commonly used in open spine surgeries. Preventive strategies are essential to avoid incidental durotomy and include avoiding excessive resection of herniated discs, maintaining low intraoperative water pressure to prevent saline from folding the dura mater, and performing careful adhesiolysis before using high-speed drills.[23,38] In our cohort, postponing ligamentum flavectomy as long as possible allowed the labile ligamentum flavum to serve as a protective barrier between surgical instruments and the dura. This strategy not only shielded the dura but also prevented the tip of the cage glider from directly stabbing neural elements. As a result, there was only one minor dural tear, which was effectively managed with an intraoperative fibrin-sealed collagen sponge tamponade, and this approach prevented any large dural tears that might have necessitated conversion to open surgery. Additionally, performing interbody fusion before ligamentum flavectomy improved workflow efficiency, ensuring that fusion was completed even if a dural tear during decompression required early termination of the endoscopic procedure.

The incidence of intervertebral infection after spine surgery ranges from approximately 0.1% to 4.5%.[38,39] Although it has been speculated that endoscopic spinal surgery, which involves continuous saline irrigation and generally causes less trauma, would have a lower incidence of infection compared to open spinal surgeries,[38] recent analyses contradict this idea. These studies indicate that the surgical approach does not independently predict the development of postoperative infection when baseline differences between patient populations are accounted for.[39] In the current cohort, there were 2 cases of postoperative vertebral infection. Possible routes for bacterial transmission include contamination introduced by a spinal needle during the initial skin puncture and transfer by endoscopic instruments due to their frequent movements in and out of the working channel. Recommended preventive strategies include making an adequate skin incision with a knife before passing the spinal needle and instruments, frequently changing gloves, and using double gloving.[40]

There are several limitations to the current study. First, the sample size of our cohort is relatively small due to the focus on uniportal FE-TLIF and the strict follow-up criteria. Second, the effect of the learning curve on the improvement of outcomes could not be eliminated, as this was not a randomized controlled trial. Finally, the current techniques do not address all possible causes of complications, such as intraoperative thermal injury, indicating that there are still areas for improvement in the GUARD technique.

CONCLUSION

In the current study, we introduced our GUARD technique for inserting cage gliders and the strategy of delayed ligamentum flavectomy. These approaches effectively reduced postoperative radicular pain in the legs at 6 weeks and significantly decreased the incidence of postoperative neurapraxia. The techniques are safe, straightforward, and cost-effective.

NOTES

Supplementary Material: Supplementary Table 1 can be found via https://doi.org/10.14245/ns.2448656.328.

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Supplementary Table 1. Complications of endoscopic lumbar interbody fusion

Variable	Total	Sentinel	GUARD	p-value
Dural tear	1	1	0	0.482
Neurapraxia	4	4	0	0.047*
Seizure	0	0	0	-
Hematoma formation	0	0	0	-
Deep infection	2	1	1	0.999
Cage migration	0	0	0	-
No. of levels	54	26	28	-

The p-values were generated using the Fisher exact test.
GUARD, glider used as a rotary device.
*$p < 0.05$, statistically significant differences.