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Unilateral Biportal Endoscopic Trans-Kambin Lumbar Interbody Fusion at the L5/S1 Level: A Consecutive Case Series With 1-Year Clinical and Radiological Outcomes

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ABSTRACT

Background: Trans-Kambin lumbar interbody fusion at L5/S1 is technically demanding because of reduced disc height, a narrow safety triangle, anatomical variability of the exiting nerve root (ENR), foraminal pathology, and interference from the iliac crest. This study evaluated the feasibility and 1-year clinical and radiological outcomes of unilateral biportal endoscopic (UBE) trans-Kambin lumbar interbody fusion at L5/S1 in a consecutive case series.

Methods: This retrospective consecutive case series included 25 patients who underwent single-level UBE trans-Kambin lumbar interbody fusion at L5/S1 between January 2023 and December 2024. Clinical outcomes were assessed using the Oswestry Disability Index and numerical rating scale scores for low back pain and leg pain. Radiological outcomes included segmental lordotic angle, slip distance, and preliminary computed tomography (CT)–based fusion assessment at 12 months. The operative strategy emphasized continuous endoscopic visualization of the ENR during corridor creation, foraminoplasty, disc space preparation, and cage insertion.

Results: Diagnoses included isthmic spondylolisthesis in 11 patients and foraminal stenosis in 9 patients. The mean preoperative disc height at the safety triangle was 2.6 ± 1.3 mm. At 12 months, segmental lordotic angle increased from 12.4° ± 6.6° to 14.6° ± 5.8° ($P = 0.0046$), and slip distance decreased from 5.5 ± 2.8 mm to 3.1 ± 2.9 mm ($P = 0.001$). Oswestry Disability Index improved from 32.5 ± 11.2 to 15.7 ± 12.8 ($P < 0.0001$). Numerical rating scale scores improved from 5.8 ± 1.6 to 2.8 ± 2.3 for low back pain ($P < 0.0001$) and from 3.8 ± 2.7 to 2.0 ± 2.2 for leg pain ($P = 0.0014$). The preliminary CT-based fusion rate at 12 months was 88.0%. No ENR injury, infection, or reoperation occurred.

Conclusions: A structured, level-specific strategy for UBE trans-Kambin lumbar interbody fusion was feasible at L5/S1 and was associated with significant clinical improvement, modest radiological correction, and an 88.0% preliminary CT-based fusion rate at 12 months. Further studies with larger cohorts and longer follow-up are needed to validate these findings.

Clinical Relevance: This study provides a level-specific framework for performing UBE trans-Kambin lumbar interbody fusion at L5/S1, a level with substantial anatomical and technical constraints.

Level of Evidence: 4.

Endoscopic Minimally Invasive Surgery

Keywords: lumbar interbody fusion, L5/S1, spondylolisthesis, unilateral biportal endoscopy, exiting nerve root, Trans-Kambin approach

INTRODUCTION

In recent years, several minimally invasive lumbar interbody fusion techniques using the trans-Kambin corridor have been introduced, and favorable clinical and radiological outcomes have been reported.[1–8] However, the existing literature has focused predominantly on the L4/5 level, whereas L5/S1 has been less frequently analyzed as a distinct anatomical and technical entity.[6,9]

The trans-Kambin approach at L5/S1 is often subject to substantial constraints due to several level-specific factors, including severe disc height collapse, narrowing of the safety triangle, anatomical variation of the exiting nerve root (ENR), osteoarthritic facet changes, and interference from a high iliac crest.[10–13] In addition, pathologies characteristic of this level, such as isthmic spondylolisthesis and severe foraminal stenosis, further complicate the application of the trans-Kambin

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approach at L5/S1. These features may not only make direct insertion of a dilator or endoscope into the disc space technically difficult but also increase the risk of exiting nerve root injury (ENRI).

Unilateral biportal endoscopy (UBE) may offer potential advantages for addressing these challenges. It allows continuous endoscopic visualization and flexible instrument manipulation through separate endoscopic and working portals. These features enable real-time assessment of the relationship between the ENR and surgical instruments during the procedure.

Nevertheless, the practical workflow for applying UBE trans-Kambin lumbar interbody fusion specifically at L5/S1 remains insufficiently defined.

Accordingly, L5/S1 should not be approached simply by applying surgical techniques commonly used at higher lumbar levels. The key technical issues at this level are how to create a safe working corridor in the presence of marked disc height collapse, severe foraminal stenosis, or slippage; how to enlarge the safety triangle in a tailored manner to permit safe cage passage; and how to assess and manage the ENR during critical procedural steps. The principal contribution of this study is not the introduction of the trans-Kambin approach or endoscopic lumbar interbody fusion itself, but rather the clinical evaluation of a structured, level-specific workflow for performing UBE trans-Kambin lumbar interbody fusion at L5/S1, with an emphasis on continuous endoscopic visualization of the ENR and tailored enlargement of the safety triangle. Therefore, this study evaluated UBE trans-Kambin lumbar interbody fusion at the anatomically challenging L5/S1 level in a consecutive single-center case series and examined its 1-year clinical and radiological outcomes. We hypothesized that this structured, level-specific workflow would permit feasible application of the trans-Kambin approach at L5/S1.

METHODS

Study Design and Patients

This single-center retrospective study evaluated 25 consecutive patients who underwent UBE trans-Kambin lumbar interbody fusion at the L5/S1 level between January 2023 and December 2024 (Figure 1). All procedures were performed by a single surgeon. This study was conducted in accordance with the Declaration of Helsinki and was approved by the institutional review board of Iwai Orthopaedic Hospital. Written informed consent for surgery and for the use of anonymized clinical data was obtained from all patients.

Diagnoses were established based on clinical symptoms, neurological findings, magnetic resonance

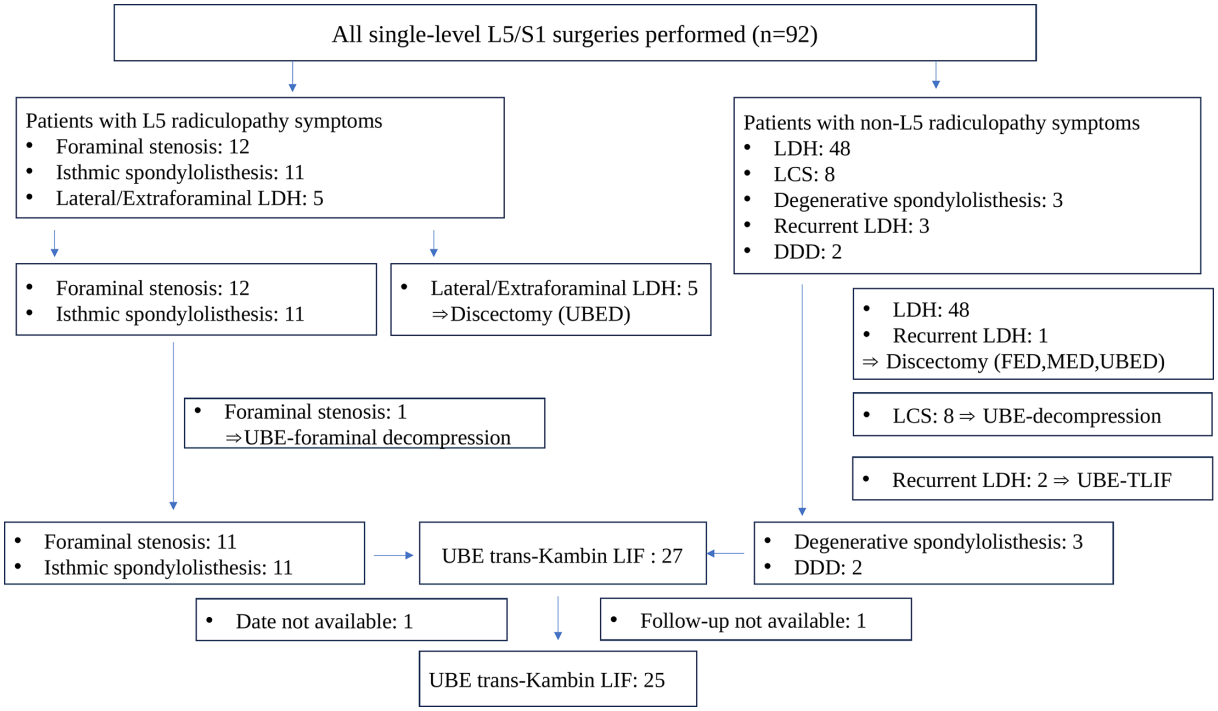

Figure 1. Flow diagram of consecutive patient enrollment for UBE trans-Kambin lumbar interbody fusion from all single-level L5/S1 surgeries (n = 92) performed between January 2023 and December 2024. DDD, degenerative disc disease; FED, full endoscopic discectomy; LCS, lumbar canal stenosis; LDH, lumbar disc herniation; LIF, lumbar interbody fusion; MED, microendoscopic discectomy; TLIF, transforaminal lumbar interbody fusion; UBE, unilateral biportal endoscopy; UBED, unilateral biportal endoscopic discectomy.

imaging, computed tomography (CT), and standing dynamic radiography. All patients underwent at least 3 months of conservative treatment before surgery.

Inclusion criteria were as follows: single-level L5/S1 pathology treated with UBE trans-Kambin lumbar interbody fusion, failure of at least 3 months of conservative treatment, availability of clinical and radiological data obtained preoperatively and at 12 months postoperatively, and a minimum follow-up period of 12 months. Exclusion criteria were multilevel fusion, infection, tumor, trauma, incomplete clinical or radiological data, and follow-up shorter than 12 months.

Surgical indications for UBE trans-Kambin lumbar interbody fusion included isthmic spondylolisthesis, degenerative spondylolisthesis, foraminal stenosis, unstable spondylosis, revision surgery, and degenerative disc disease. Patients with concomitant spinal canal stenosis were eligible only when the stenosis was mild, defined as Schizas grade A or B on magnetic resonance imaging.[14]

Surgical Technique

Choice of Approach Side and Skin Incision Design

The approach side was selected based on technical ease. Caudal insertion of the endoscope may frequently be limited by interference between the endoscope itself and the iliac crest, resulting in restricted endoscopic maneuverability (Figure 2A). Therefore, careful preoperative planning and familiarity with this maneuver are required.

The craniocaudal distance between the working portal and the endoscopic portal was maintained at approximately 30 mm, regardless of patient body habitus, and the endoscopic portal was created slightly more medially. In most cases, the working portal was placed 7 to 12 cm lateral to the midline, and the working portal trajectory was designed to aim toward the contralateral corner of the disc space (Figure 2b). The inferior articular process was preserved whenever possible.

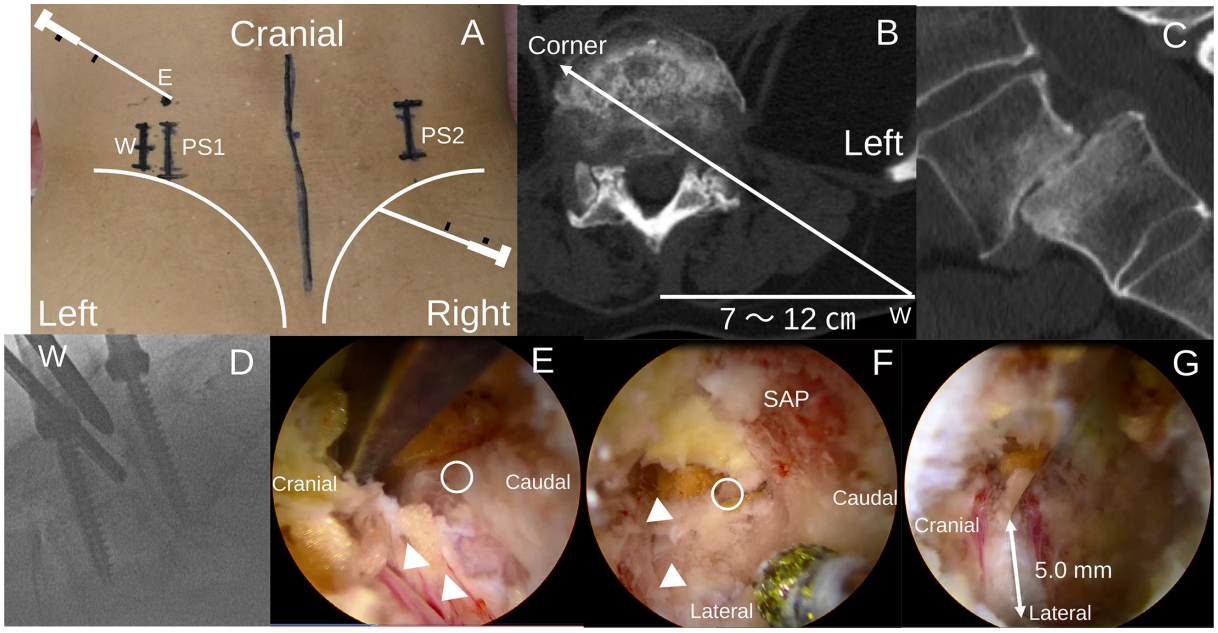

Figure 2. Skin incision design and trans-Kambin approach. (A) W indicates the working portal. E indicates the endoscopic portal. PS indicates the pedicle screw incision. Arcs indicate the iliac crest. The craniocaudal distance between W and E is approximately 30 mm regardless of patient body habitus, and E is created slightly more medially. When the endoscope is inserted from the caudal side, it may interfere with the iliac crest and therefore requires familiarity with the technique. (B) W indicates the working portal. In most cases, W is created 7–12 cm lateral to the midline, forming an approach angle of approximately 30°–40°. The inferior articular process must be consistently preserved. (C) Sagittal computed tomography image of grade II isthmic spondylolisthesis. The disc height is completely collapsed. (D) Intraoperative lateral fluoroscopic image. W indicates the working portal. W is created along the tangential line of the intervertebral disc space. Using the dilation technique, initial access is established at the superior margin of the S1 vertebral body near the base of the S1 superior articular process (SAP), which serves as a relatively safe initial anatomical target. (E) White circle indicates the superior margin of the S1 vertebral body. Triangles indicate the exiting nerve root (ENR). Soft tissues are bluntly detached along the surface of the S1 vertebral body while confirming the position of the ENR to identify the L5/S1 disc space, which serves as the entry point for chisel insertion. (F) SAP indicates the SAP of S1. White circle indicates the superior margin of the S1 vertebral body. Triangles indicate the ENR. Foraminoplasty is performed under continuous endoscopic visualization to safely enlarge the safety triangle while confirming the position of the ENR. (G) A fissure is created in the annulus fibrosus with a chisel.

Operative Setup

All procedures were performed under general anesthesia with the patient in the prone position on a radiolucent operating table. A 30° oblique-viewing endoscope with an outer diameter of 3.8 mm was used together with a bipolar radiofrequency probe, a 3.0-mm diamond bur, serial dilators, and standard spinal instruments. Continuous gravity-based saline irrigation was maintained throughout the procedure, and intraoperative neuromonitoring, including somatosensory evoked potentials, electromyography, and free-run electromyography, was used routinely.

Step 1. UBE Trans-Kambin Approach

Contralateral percutaneous pedicle screws were inserted as the first step of the procedure. The UBE trans-Kambin approach was performed using a previously described dilation technique.[15] When the intervertebral disc space was too narrow to allow direct puncture (Figure 2C and D), an 18-gauge spinal needle was inserted at the base of the S1 superior articular process (SAP) through the working (W) portal, followed by guidewire placement and serial dilation (Figure 2D). The dilation technique facilitated triangulation and expansion of the paravertebral muscles, enabling minimally invasive creation of a working space. Advancement of the endoscope along the guidewire or dilator provided a stable surgical trajectory. In cases of marked disc space narrowing where the ENR was located close to the disc space, soft tissues were gently detached along the bony surface to expose the disc surface and accurately identify the osteotome entry point (Figure 2E).

Step 2. Foraminoplasty

Foraminoplasty was performed to enlarge the safety triangle under continuous endoscopic visualization of the ENR (Figure 2F). After creating a small fissure in the annulus fibrosus with a chisel (Figure 2G), fluoroscopy was performed to confirm that the forceps had reached the contralateral corner of the disc space (Figures 2B and 3A). If the forceps could not reach the contralateral corner, additional foraminoplasty or complete resection of the SAP was performed, and the insertion point was shifted medially. The same strategy was applied when the ENR overlapped the lateral aspect of the disc space.

Step 3. Disc Height Restoration and Slip Correction

To avoid endplate injury, a flat-type shaver was used at both the ipsilateral and contralateral rims to achieve mild correction of slippage and restoration of disc height (Figure 3A–C). By rotating the shaver at both the ipsilateral and contralateral rims, disc height was restored and slippage was corrected (Figure 3C and D). The contralateral rod was then provisionally secured to maintain this correction (Figure 3C and D). Extensive endplate preparation was performed through both the approach-side percutaneous pedicle screw skin incision (PS1) and the working portal (Figure 3E and F).

Step 4. Cage Insertion

After placement of artificial bone graft material in the anteroventral portion of the disc space (Figure 4A), the planned cage size was evaluated with a trial cage or shaver under endoscopic visualization to confirm the absence of contact with the ENR (Figure 4B). During this step, the endoscopic view was maintained in the 6 to 7 o'clock orientation to ensure continuous visualization of the ENR. The cage was then inserted percutaneously toward the contralateral corner under combined endoscopic and fluoroscopic guidance, advancing along the lateral surface of the S1 SAP to enter the disc space in a controlled manner (Figure 4C). Anteroposterior fluoroscopic views confirmed that the tip of the cage had passed the midline (Figure 4C), while the endoscopic view verified that the caudal end of the cage had entered the intervertebral disc space appropriately (Figure 4D). After intentional release of the provisional rod fixation, the cage was advanced anteroventrally with an angled impactor through the approach-side pedicle screw incision (Figure 4E–H). Additional artificial bone graft material was packed into the posterior portion of the disc space.

Following confirmation of hemostasis, all instruments were removed without drain placement. Finally, percutaneous pedicle screws were inserted on the approach side to complete bilateral fixation.

Radiological Evaluation

Radiological parameters were evaluated preoperatively and at 12 months postoperatively. Slip distance and segmental lordotic (SL) angle were assessed to evaluate radiographic changes after surgery. SD was measured only in patients with preoperative spondylolisthesis, defined as a slip distance of ≥2 mm. Postoperative CT scans were reviewed to assess the extent of foraminoplasty by evaluating the resection status of the S1 SAP. The extent of SAP resection was categorized as complete preservation of the facet joint surface, partial resection, or complete resection.

Fusion status at 12 months postoperatively was evaluated using multiplanar reconstructed CT images according to the method described by Segi et al.[16]

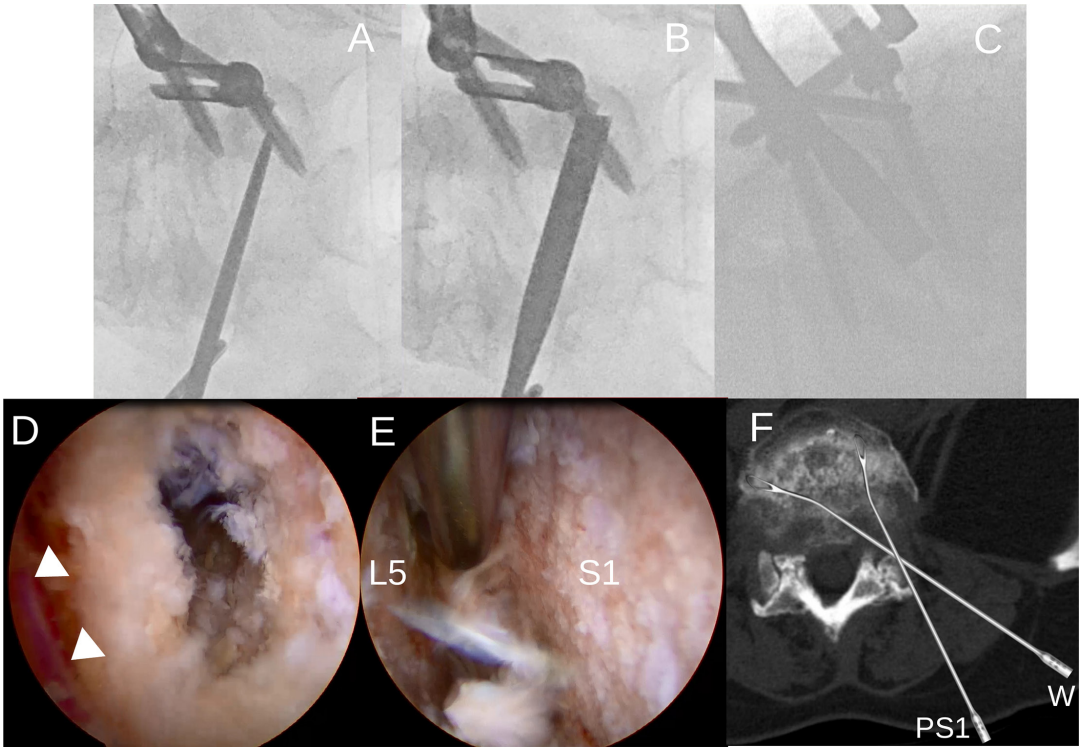

Figure 3. Endplate preparation following correction of spondylolisthesis and restoration of disc height. (A) Anteroposterior fluoroscopy is performed to confirm that the shaver has reached the contralateral rim. (B and C) The shaver is rotated clockwise from both the ipsilateral and contralateral rim portions to sequentially correct spondylolisthesis and restore disc height. Once the planned correction and disc height restoration are achieved, the contralateral rod is provisionally fixed. (D) Triangles indicate the exiting nerve root. The disc space remains sufficiently expanded after shaver removal. (E) Adequate preparation can be performed under direct endoscopic visualization. (F) W indicates the working portal, and PS1 indicates the approach side pedicle screw skin incision. Endplate preparation from both W and PS1 is allowed for broad and thorough endplate coverage.

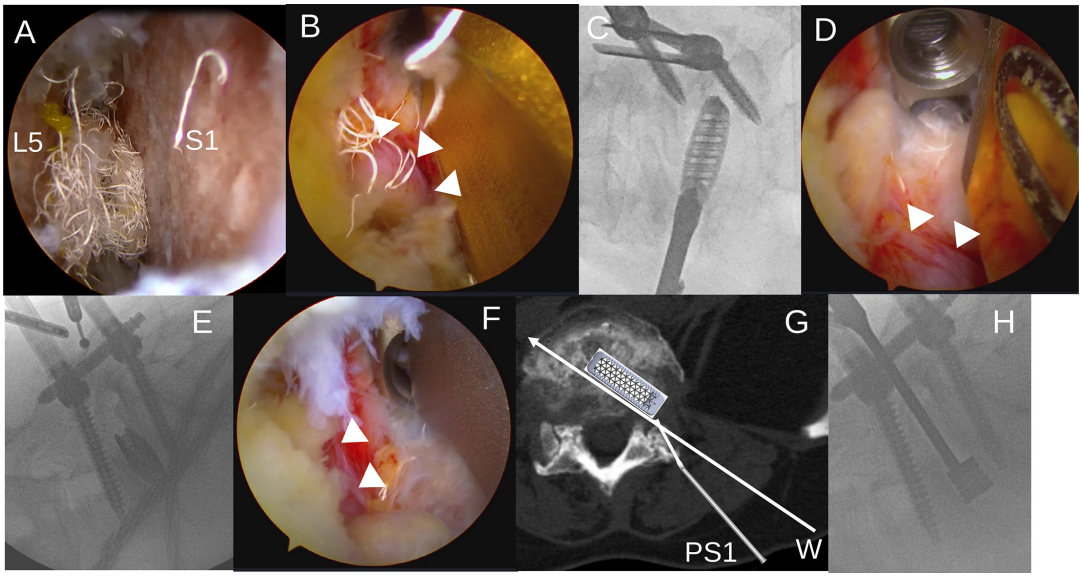

Figure 4. Cage insertion. (A) Bone graft material is placed in the anteroventral portion of the disc space. (B) Triangles indicate the exiting nerve root (ENR). The planned cage size is assessed with a trial shaver to evaluate its relationship with the ENR. If contact with the ENR is identified, additional foraminoplasty or further resection of the S1 superior articular process is performed. (C) Anteroposterior fluoroscopic view after cage insertion, showing that the cage tip crosses the midline. (D) Triangles indicate the ENR. Endoscopic visualization confirms that the caudal end of the cage passes beyond the ENR without contact. (E) Lateral fluoroscopic view after cage insertion. (F) Triangles indicate the ENR. With the rod intentionally released from provisional fixation, a curved impactor is introduced through the approach-side pedicle screw skin incision to rotate the cage. (G) PS1 indicates the approach-side pedicle screw skin incision, and W indicates the working portal. The axial computed tomography image corresponds to the schematic illustration shown in panel F. (H) Lateral fluoroscopic view after cage rotation.

Instability was defined as the presence of a vacuum sign, clear zones around all 4 pedicle screws, or a local range of motion greater than 5°. Segments without any of these findings were considered to show preliminary CT-based fusion at 12 months.

Radiographic measurements and instability assessments were independently performed by 2 spine surgeons. Mean values were used for quantitative parameters, and disagreements regarding instability were resolved by consensus.

Clinical Evaluation

Clinical outcomes were assessed using the Oswestry Disability Index and numeric rating scale (NRS) scores for low back pain and leg pain. These measurements were recorded preoperatively and at 12 months postoperatively.

Statistical Analysis

Descriptive statistics are presented as mean ± SD for continuous variables and as counts with percentages for categorical variables. Preoperative and postoperative clinical outcomes were compared using paired *t* tests after confirmation of normality. Radiographic parameters were analyzed using the Wilcoxon signed-rank test because of the small sample size and non-normal distribution of the data. A P value of <0.05 was considered statistically significant. All statistical analyses were performed using Stata/SE software (version 18.0; StataCorp LLC, College Station, TX, USA).

RESULTS

Patient Characteristics

A total of 25 patients were included in this study. The mean age was 58.2 ± 9.2 years (range, 43–75 years), and the cohort included 16 men and 9 women. The mean body mass index was 23.8 ± 3.2 kg/m² (range, 17.7–31.4 kg/m²). Twenty-two patients underwent primary surgery, and 3 underwent revision surgery.

The underlying diagnoses were isthmic spondylolisthesis in 11 patients, including 9 Grade 1 and 2 Grade 2 cases; foraminal stenosis in 9 patients; degenerative spondylolisthesis in 3 patients; and degenerative disc disease in 2 patients. The mean disc height at the safety triangle was 2.6 ± 1.3 mm (range, 1–5 mm; Table 1).

Table 1. Patient demographics and diagnoses (N = 25).

Variable	Value
Age, y, mean ± SD (range)	58.2 ± 9.2 (43–75)
Sex, *n*	
Men	16
Women	9
BMI, mean ± SD (range)	23.8 ± 3.2 (17.7–31.4)
Primary surgery, *n*	22
Revision surgery, *n*	3
Diagnosis, *n*	
Isthmic spondylolisthesis	
Grade 1	9
Grade 2	2
Foraminal stenosis	9
Degenerative spondylolisthesis, Grade 1	3
Disc degenerative disease	2
Disc height, mm, mean ± SD (range)	2.6 ± 1.3 (1–5)

Abbreviation: BMI, body mass index.

Operative Outcomes and Complications

The mean operative time was 112.9 ± 18.4 minutes (range, 80–145 minutes), and the mean postoperative hospital stay was 7.2 ± 1.4 days (range, 2–8 days). Facet joint resection of the SAP was complete in 7 cases (28.0%), partial in 3 cases (12.0%), and preserved in 15 cases (60.0%). The cages used were UNIOS PL Spacer in 23 patients, CoRoent AT in 1 patient, and Adaptix in 1 patient.

No cases of ENRI, infection, or reoperation occurred during the follow-up period. Cage migration occurred in 1 patient but did not require revision surgery during the follow-up period (Table 2).

Radiological Outcomes

At 12-months postoperative follow-up, the mean segmental lordotic angle significantly increased from 12.4° ± 6.6° preoperatively to 14.6° ± 5.8° (P = 0.0046), with a mean change of +2.2° ± 3.4°. In the 14 patients with measurable preoperative spondylolisthesis, the mean SD significantly decreased from 5.5 ± 2.8 mm preoperatively to 3.1 ± 2.9 mm at 12 months (P = 0.001), with a mean change of −2.4 ± 1.7 mm. The preliminary CT-based fusion rate at 12 months was 88.0% (Table 3; Figure 5A–C).

Clinical Outcomes

Clinical outcomes significantly improved at 12 months postoperatively. The mean Oswestry Disability Index score decreased from 32.5 ± 11.2 preoperatively to 15.7 ± 12.8 at 12 months (P < 0.0001). The mean NRS score for low back pain decreased from 5.8 ± 1.6 to 2.8 ± 2.3 (P < 0.0001), and the mean NRS score for leg pain decreased from 3.8 ± 2.7 to 2.0 ± 2.2 (P = 0.0014; Table 3).

DISCUSSION

In this consecutive case series, UBE trans-Kambin lumbar interbody fusion at L5/S1 was feasible and was associated with significant clinical improvement,

Table 2. Operative outcomes and clinical results.

Variable	Value
Operative parameters	
Operative time, min, mean ± SD (range)	112.9 ± 18.4 (80–145)
Length of postoperative hospital stay, d, mean ± SD (range)	7.2 ± 1.4 (2–8)
Facet joint resection of SAP, *n/N* (%)	
Complete	7/25 (28.0%)
Partial	3/25 (12.0%)
Preserved	15/25 (60.0%)
Cage used, *n*	
UNIOS PL Spacer (36 × 10 mm × 6°)	23
CoRoent AT (30 × 11 mm × 8°)	1
Adaptix (38 × 10 mm × 0°)	1
Perioperative and 12-mo postoperative complications, *n*	
Exiting nerve root injury	0
Infection	0
Revision surgery	0
Cage migration	1

Abbreviation: SAP, superior articular process.

modest radiological correction, and an 88.0% preliminary CT-based fusion rate at 12 months. No ENRI, infection, or reoperation occurred during the follow-up period. The principal contribution of this study is the clinical evaluation of a structured, level-specific workflow for applying this procedure at L5/S1, emphasizing continuous endoscopic visualization of the ENR and tailored enlargement of the safety triangle.

This distinction is clinically important because most previous reports on trans-Kambin lumbar interbody fusion have focused predominantly on L4/L5, whereas L5/S1 has been less consistently addressed as a distinct anatomical and technical entity.[17–22]

In a recent systematic review of trans-Kambin lumbar interbody fusion, only 45 of 257 patients (17.5%) underwent surgery at L5/S1, whereas 181 (70.4%) were treated at L4/L5 and 31 (12.1%) at other lumbar levels.[6] In addition, the underlying pathologies were predominantly degenerative spondylolisthesis (116 cases, 43.8%), lumbar disc herniation or instability (64 cases, 24.2%), degenerative disease (62 cases, 23.4%), and discogenic pain (14 cases, 5.3%), whereas isthmic spondylolisthesis accounted for only 9 cases (3.4%). By contrast, our cohort differed from many previously reported series in its pathological profile: 11 of 25 (44.0%) patients had isthmic spondylolisthesis, and 9 of 25 (36%) had foraminal stenosis. This is relevant because both pathologies are particularly characteristic of L5/S1 and may further constrain the trans-Kambin corridor through slip, foraminal narrowing, and marked disc height collapse. Moreover, in our cohort, the mean disc height within the safety triangle was only 2.6 mm, indicating that access to the disc space was markedly restricted preoperatively. Taken together, these findings support the view that L5/S1 should not be regarded simply as another indication for standard trans-Kambin techniques used at higher lumbar levels, but rather as a level requiring specific intraoperative strategies.

ENRI remains the most critical complication associated with the trans-Kambin approach and is a major contributor to technical difficulty at L5/S1. Although most cases are transient, reported rates of ENRI or postoperative radiculitis range from 5% to 35%.[1,17,18,23–27]

This risk is thought to be greatest during the trans-Kambin approach and cage insertion, particularly when the safety triangle has not been adequately enlarged. In this context, the central concept of our strategy is continuous endoscopic visualization of the ENR throughout critical procedural steps, enabling real-time assessment of its position and helping guide safe corridor creation.

At L5/S1, slippage and marked disc height collapse may make direct guidewire or dilator insertion through the safety triangle technically difficult and increase the risk of ENRI. Although slip correction and disc space distraction using pedicle screws and rods may facilitate access to the disc space, this strategy has practical limitations at this level. In particular, an approach-side rod and the iliac crest may obstruct endoscope insertion into the safety triangle and restrict endoscopic maneuverability. Accordingly, our approach first emphasizes reaching the most consistently safe anatomical regions,

Table 3. Radiological and clinical outcomes.

Outcomes	*n*	Preoperative, Mean ± SD (Range)	Postoperative (12 mo), Mean ± SD (Range)	Change, Mean ± SD	*P*
Radiologic					
SL (°)	25	12.4 ± 6.6 (−2.6–23.0)	14.6 ± 5.8 (6.3–29.2)	+2.2 ± 3.4	0.0046
Slip distance (mm)	14	5.5 ± 2.8 (2.0–12.0)	3.1 ± 2.9 (0.0–7.5)	−2.4 ± 1.7	0.001
Clinical					
ODI score	25	32.5 ± 11.2 (4.4–60)	15.7 ± 12.8 (0–46.7)	−16.8 ± 15.7	<0.0001
NRS score	25				
Leg pain		3.8 ± 2.7 (0–8)	2.0 ± 2.2 (0–7)	−1.8 ± 2.5	0.0014
Back pain		5.8 ± 1.6 (2–8)	2.8 ± 2.3 (0–8)	−2.9 ± 2.9	<0.0001

Abbreviations: NRS, numeric rating scale; ODI, Oswestry Disability Index; SL, segmental lordotic angle.
Note: Clinical outcomes were analyzed using a paired *t* test. Radiographic parameters were analyzed using the Wilcoxon signed-rank test.

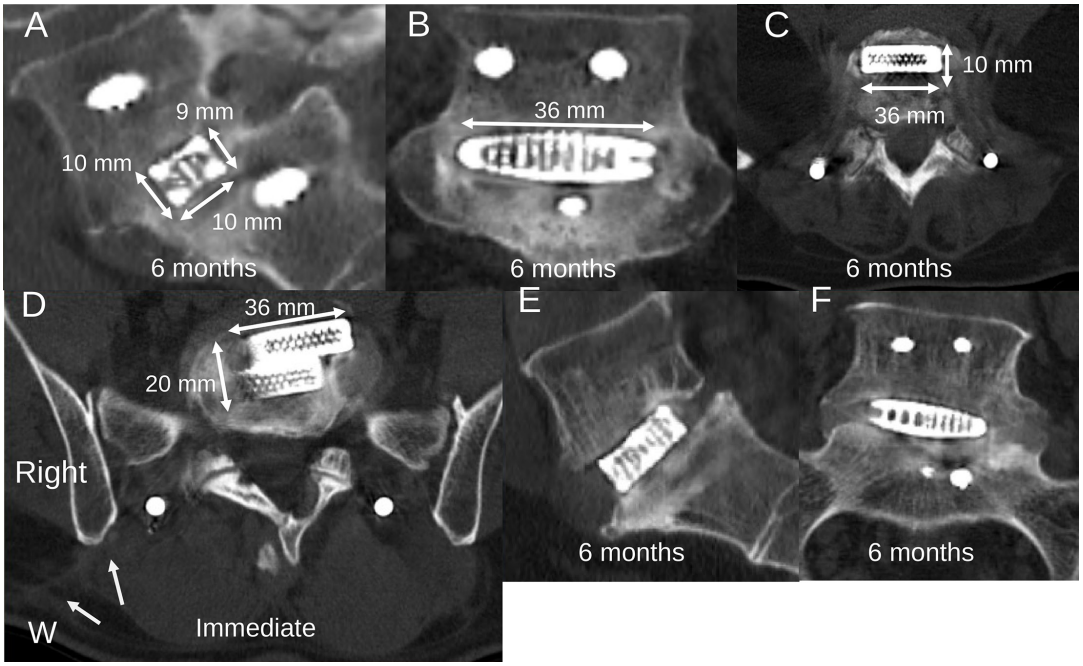

Figure 5. Postoperative computed tomography (CT) images of representative cases with grade II and grade I isthmic spondylolisthesis. (A and B) Bone fusion is observed on sagittal and coronal CT images. (C) The axial image demonstrates complete preservation of the bilateral facet joints. (D–F) Postoperative CT images demonstrate the insertion of 2 cages. Arrows indicate the trans-Kambin corridor. W indicates the working portal. Postoperative CT images obtained 6 months postoperatively demonstrate bony union.

namely the superior endplate of the S1 vertebral body and the base of the SAP (Figure 2D).

Adequate enlargement of the safety triangle is a critical step for successful trans-Kambin lumbar interbody fusion. In our approach, effective enlargement was achieved in 2 dimensions: craniocaudally through correction of slippage and restoration of disc height using rotational shaver manipulation, and mediolaterally through resection of the S1 SAP as part of foraminoplasty. Importantly, the size of the safety triangle required for safe cage insertion was not predefined but was determined intraoperatively. Slippage correction, disc height restoration, and foraminoplasty were dynamically tailored based on the endoscopic relationship between the ENR and surgical instruments, allowing creation of an optimized, patient-specific working corridor.

Consistent with this concept, postoperative CT demonstrated variable extents of SAP resection among patients (Table 2). This finding suggests that complete SAP resection was selectively performed in cases with an increased risk of ENRI or when anatomical factors, such as a high iliac crest, made the approach technically difficult.

In general, protective devices such as sleeves, sheaths, or nerve retractors are commonly used to prevent ENRI. However, based on a cadaveric study, Phillips et al reported that the dorsal root ganglion is highly sensitive to pressure and traction injury, indicating that excessive nerve root retraction or mechanical irritation from surgical instruments may increase the risk of neural injury, particularly at anatomically constrained levels such as L5/S1.[28] Therefore, our strategy prioritizes continuous endoscopic visualization to maintain real-time awareness of the ENR position within the safety triangle. Based on this real-time assessment, we considered using a nerve retractor only when contact persisted despite complete SAP resection, thereby minimizing the need for excessive nerve root manipulation.

Our technique also provided several practical advantages. Endplate preparation could be performed through both the approach-side pedicle screw incision and the working portal, which increased the flexibility and maneuverability of the UBE procedure (Figure 3F). In addition, the ipsilateral facet joint surface was preserved in most cases, despite the need for tailored enlargement of the safety triangle (Table 2). In selected cases, insertion of 2 cages was also feasible (Figure 5D–F). These findings suggest that UBE trans-Kambin lumbar interbody fusion may allow flexible disc space preparation and cage placement while adapting the working corridor to patient-specific anatomical constraints at L5/S1.

This study has several limitations. Its retrospective single-center design and small sample size may limit the generalizability of the findings. The learning curve was not formally evaluated, and all procedures were

performed by a single surgeon experienced in UBE surgery. Therefore, the findings may not be directly generalizable to surgeons at an earlier stage of adopting this technique. In addition, the cohort included heterogeneous L5/S1 pathologies, and subgroup-specific conclusions cannot be drawn. The CT-based fusion assessment at 12 months should be considered preliminary, and longer-term follow-up is required. Finally, given the absence of a comparative group, the relative effectiveness of UBE trans-Kambin lumbar interbody fusion compared with other lumbar interbody fusion techniques remains unclear.

CONCLUSION

UBE trans-Kambin lumbar interbody fusion at L5/S1 was feasible in this consecutive case series and was associated with significant clinical improvement, modest radiological correction, and an 88.0% preliminary CT-based fusion rate at 12 months. The structured strategy emphasized continuous endoscopic visualization of the ENR and tailored enlargement of the safety triangle under the anatomical constraints of L5/S1. Further studies with larger cohorts and longer follow-up are needed to validate these findings.

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