Clinical Study

ASJ

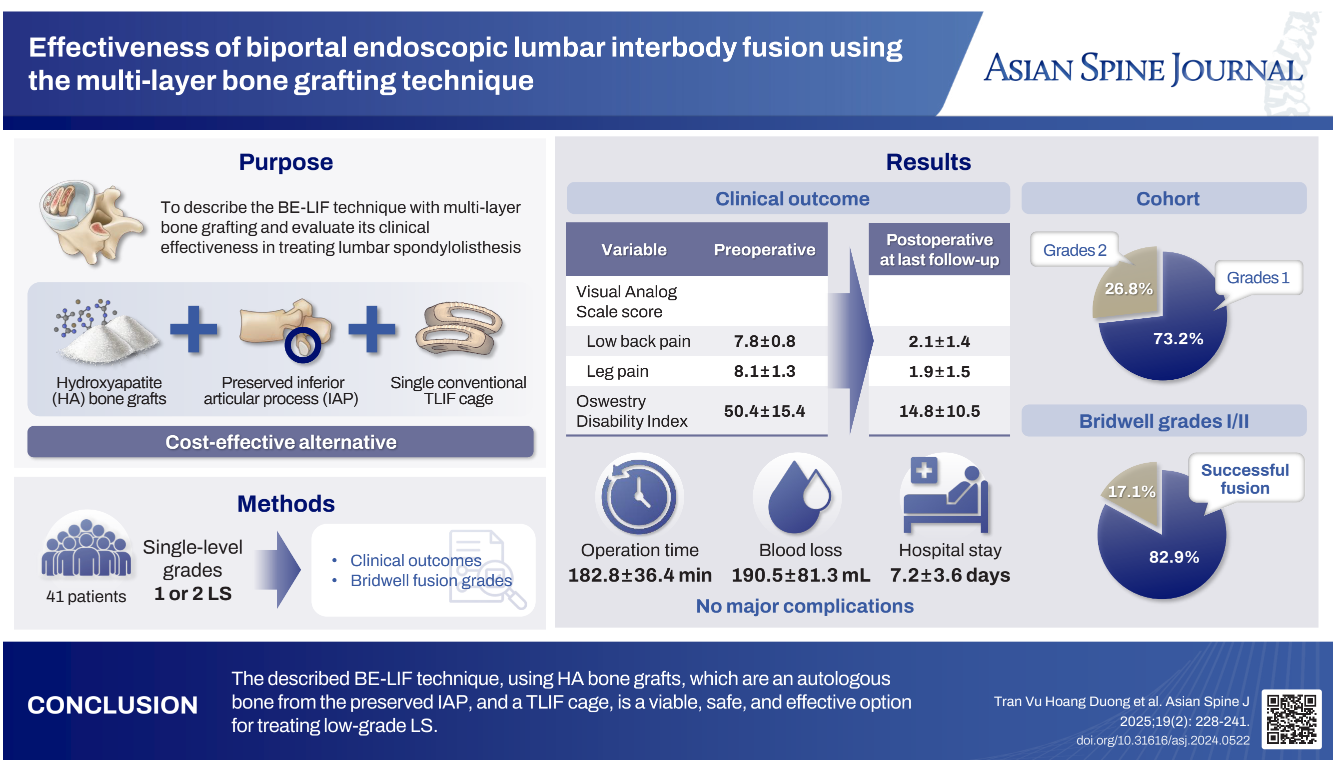
Asian Spine J. 2025;19(2): 228-241
https://doi.org/10.31616/asj.2024.0522
PISSN 1976-1902 • eISSN 1976-7846

Special issue

Effectiveness of biportal endoscopic lumbar interbody fusion using the multi-layer bone grafting technique: a retrospective study from Vietnam

Tran Vu Hoang Duong[1,2], Pham Anh Tuan[2,3], Huynh Van Vu[1], Chu Van Lam[1], Le Tan Linh[1], Phan Duy[4], Wongthawat Liawrungrueang[5]

[1]Department of Neurosurgery, Xuyen A General Hospital, Ho Chi Minh City, Vietnam
[2]Faculty of Medicine, University of Medicine and Pharmacy at Ho Chi Minh City, Ho Chi Minh City, Vietnam
[3]Department of Neurosurgery, Nguyen Tri Phuong Hospital, Ho Chi Minh City, Vietnam
[4]Department of Neurosurgery, Vinmec Central Park International Hospital, Ho Chi Minh City, Vietnam
[5]Spine Division & Head, Orthopaedics Department, School of Medicine, University of Phayao, Phayao, Thailand



Received Dec 7, 2024; **Revised** Mar 10, 2025; **Accepted** Mar 10, 2025
Corresponding author: Tran Vu Hoang Duong
Department of Neurosurgery, Xuyen A General Hospital, 42, National Highway 22, Cu Chi District, Ho Chi Minh City, Vietnam
Tel: +84-987232045, **Fax:** +84-2837966999, **E-mail:** tranvuhoangduong@gmail.com; tvhduong.ncs.ngoai24@ump.edu.vn

Effectiveness of biportal endoscopic lumbar interbody fusion using the multi-layer bone grafting technique: a retrospective study from Vietnam

Tran Vu Hoang Duong[1,2], Pham Anh Tuan[2,3], Huynh Van Vu[1], Chu Van Lam[1], Le Tan Linh[1], Phan Duy[4], Wongthawat Liawrungrueang[5]

Study Design: A retrospective cohort study.

Purpose: This study aimed to describe the surgical technique of biportal endoscopic (BE) lumbar interbody fusion (LIF) using a multi-layer bone grafting method and to investigate its clinical effectiveness in treating patients with grade I or II lumbar spondylolisthesis (LS).

Overview of Literature: Previous studies have described BE-LIF; however, these reports predominantly originate from advanced centers in developed countries, using sophisticated implants such as dual transforaminal LIF (TLIF), oblique LIF, or titanium cages. In contrast, the described method utilizes hydroxyapatite (HA) bone grafts and autologous bone obtained from the preserved inferior articular process (IAP), combined with a single conventional TLIF cage, which provides a cost-effective alternative.

Methods: This study included 41 patients with single-level grades 1 or 2 LS from February 2023 to February 2024. Clinical outcomes were assessed using the Visual Analog Scale (VAS) for back and leg pain and the Oswestry Disability Index (ODI). Bridwell fusion grades were evaluated via lumbar spine computed tomography performed 6 months postoperatively.

Results: Over a mean follow-up period of 10.6 months (range, 7–18 months), significant improvements were observed in VAS scores for low back pain (from 7.8±0.8 to 2.1±1.4) and leg pain (from 8.1±1.3 to 1.9±1.5) as well as ODI scores (from 50.4±15.4 to 14.8±10.5). The cohort consisted of patients with grades 1 (73.2%) and 2 LS (26.8%) at L4–L5 (58.6%), L5–S1 (34.1%), and L3–L4 (7.3%) levels. The mean operation time was 182.8±36.4 minutes, with a mean intraoperative blood loss of 190.5±81.3 mL and a mean hospital stay of 7.2±3.6 days. Successful fusion (Bridwell grades I/II) was achieved in 82.9% of the cases, with a 4.9% incidence of cage subsidence. Minor complications included durotomies in two patients (4.9%), whereas no major complications, such as nerve root injury, hardware-related issues, or postoperative infections, were reported.

Conclusions: The described BE-LIF technique, using HA bone grafts, which are an autologous bone from the preserved IAP, and a TLIF cage, is a viable, safe, and effective option for treating low-grade LS. This approach achieves favorable clinical outcomes and high fusion rates, which provides a cost-effective alternative to advanced surgical implants.

Keywords: Minimally invasive spine surgery; Biportal endoscopic lumbar interbody fusion; Lumbar spondylolisthesis; Bone grafting

Introduction

Lumbar interbody fusion (LIF) is a well-established, safe, and effective technique for managing lumbar spondylolisthesis (LS) [1-3]. Among the different surgical approaches, transforaminal lumbar interbody fusion (TLIF) is particularly advantageous. This procedure utilizes a unilateral approach, which facilitates the placement of fusion materials through an expanded Kambin's triangle, thereby minimizing the risk of nerve root injury. Further, TLIF has achieved high fusion rates and favorable reduction parameters [1,3]. Technology and surgical instrumentation advancements have significantly broadened the indications for minimally invasive spine surgery. Among these advancements, biportal endoscopic spine surgery (BESS) has been recognized as a highly effective technique [4,5]. BESS has been successfully applied to various lumbar spinal degenerative conditions, including discectomy, unilateral laminotomy for bilateral decompression, foraminotomy, and interbody fusion, all of which have exhibited consistently good clinical outcomes [5,6]. The distinct separation of the working and viewing channels in BESS provides several advantages, including enhanced magnification, flexible visualization, and improved surgical efficiency [6,7].

Experts at advanced centers have described biportal endoscopic lumbar interbody fusion (BE-LIF) which has demonstrated excellent clinical and radiological outcomes, particularly in terms of fusion [8-10]. Several modifications have been proposed to improve the safety and efficacy of this procedure, utilizing the advantages of BESS to improve successful fusion rates [8,9,11,12]. Strategies include the use of double TLIF [8] or oblique lumbar interbody fusion (OLIF) cages [9] to increase the volume of bone graft material within the disc space and maximize the contact area between the graft and exposed bony endplates. Further, the application of materials, such as titanium-coated cages, bone morphogenetic proteins, and meticulous endplate preparation before graft placement, has been emphasized [8,12,13]. Further improvements in the procedural techniques aim to mitigate autograft bone migration in the continuous inflow–outflow water environment inherent to BESS.

This study describes a step-by-step BE-LIF technique that is specifically designed for resource-limited settings in managing LS. The procedure uses a multilayered bone grafting approach, combining hydroxyapatite (HA) bone grafts with resected inferior articular process (IAP) fragments, which are repurposed as structural blocks, and a traditional TLIF cage filled with local autologous bone. The technique promotes bridging bone formation both within and around the cage by strategically layering these diverse grafting materials. The *en-bloc* IAP further improves the construct stability, increases the contact area with the endplates, and serves as a physical barrier to prevent graft migration. Beyond assessing clinical outcomes, the study investigates bone fusion efficacy using postoperative lumbar spine computed tomography (CT) imaging, thereby providing comprehensive evidence of the technique's clinical use and effectiveness.

Materials and Methods

This retrospective cohort study included patients who underwent a single-level BE-LIF from February 2023 to February 2024. This study adhered to the Declaration of Helsinki and obtained approval from the Ethics Committee and Institutional Review Board (IRB) of Xuyen A General Hospital Medical Research Council (IRB approval no., 31/2024/QD-BVXA). The requirement for informed consent from individual patients was omitted because of the retrospective design of this study.

Inclusion criteria and patient selection

Inclusion criteria included the patient's confirmed LS diagnosis with significant symptoms, such as low back pain, radiating leg pain, and motor or sensory deficits, imaging results from magnetic resonance imaging and flexion–extension X-rays consistent with clinical symptoms, demonstrating single-level LS graded I or II per the Meyerding classification, and failure of conservative treatment for at least 6 weeks. The exclusion criteria included patients having lumbar spine infections, tumors, trauma, and previous lumbar spine surgery. A single highly experienced spine surgeon performed all procedures using a conventional TLIF cage at the affected level, with no additional costs compared to traditional open or minimally invasive fusion techniques.

Surgical technique and instrumentation

Anesthesia and position

In a radiolucent spine table, the patient was placed under general endotracheal anesthesia in the prone position on a Wilson frame to reduce abdominal pressure. We used a draping technique with waterproof adhesive sheets, followed by a sterile drape kit, to isolate the surgical field and prevent water leakage onto the patient during the operation. The table height was adjusted to facilitate easy fluoroscope usage for obtaining both anteroposterior (AP) and lateral views (Fig. 1E). The surgeon is right-handed; thus, we stand on the patient's left side in most cases. This position facilitates access to the working space, minimizes paraspinal muscle invasion, especially the multifidus muscle, and ensures a clear surgical field view. We used a 30° scope to expand the viewing.

Skin incisions and creating portals

The surgical level was determined using fluoroscopic images in both AP and lateral views, focusing on determining the skin incision for the working portal to facilitate decompression and cage insertion. In the AP view, a 1.5 cm longitudinal skin incision was aligned along the line connecting the lateral aspects of the two pedicles, with the midpoint of the incision corresponding to a line through the lower endplate. The scope portal is placed approximately 2.5–3 cm from the working portal, cranially on the left and caudally on the right, with a longitudinal incision to help in subsequent percutaneous pedicle screw fixation (PPSF) (Fig. 1B, D). After adequately incising the lumbar fascia, serial dilators are used to detach the multifidus muscle from the cranial lamina and access the plane between the multifidus and longissimus dorsi muscles from the working portal incision. Larger dilators tend to move laterally from the midline toward the facet joint as they are introduced, and each initially makes contact on the lamina's bone surface. Smaller dilators were used to establish triangulation for the scope portal, with the distal contact

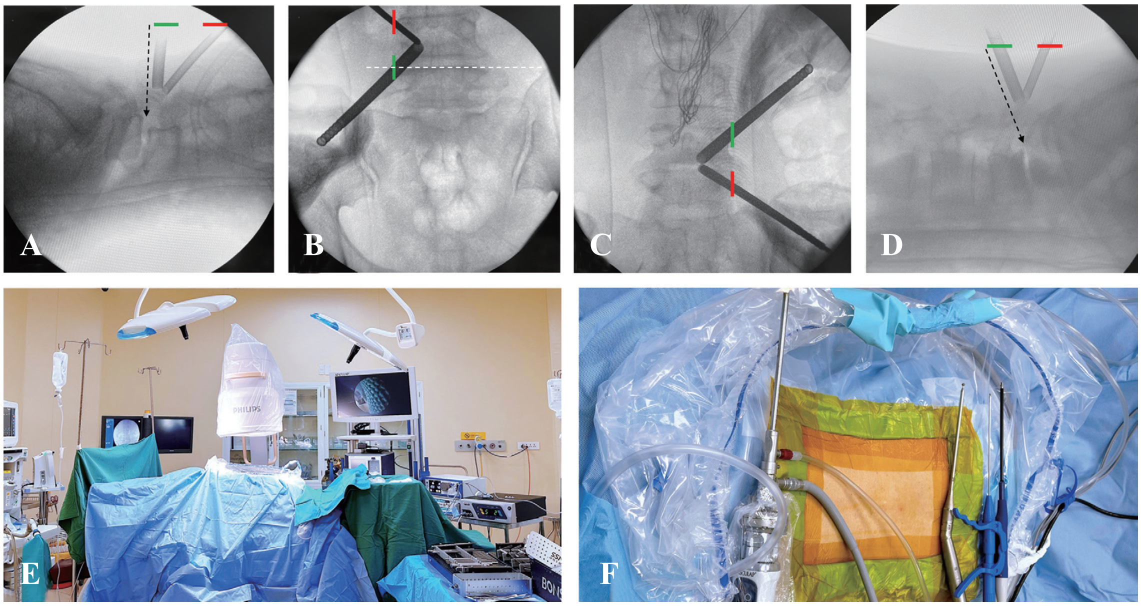


Fig. 1. **(A, B)** Skin incisions for creating the working portal (green line), of which dilator parallel to the disc space (dashed black arrow). The midpoint of this incision corresponds to a line drawn through the lower endplate (dotted white line). And the scope portal (red line) is shown for the left-side approach. **(C, D)** The same configuration for the right-side approach. **(E)** Operating room setup, including the fluoroscope placement. **(F)** Surgical field overview.

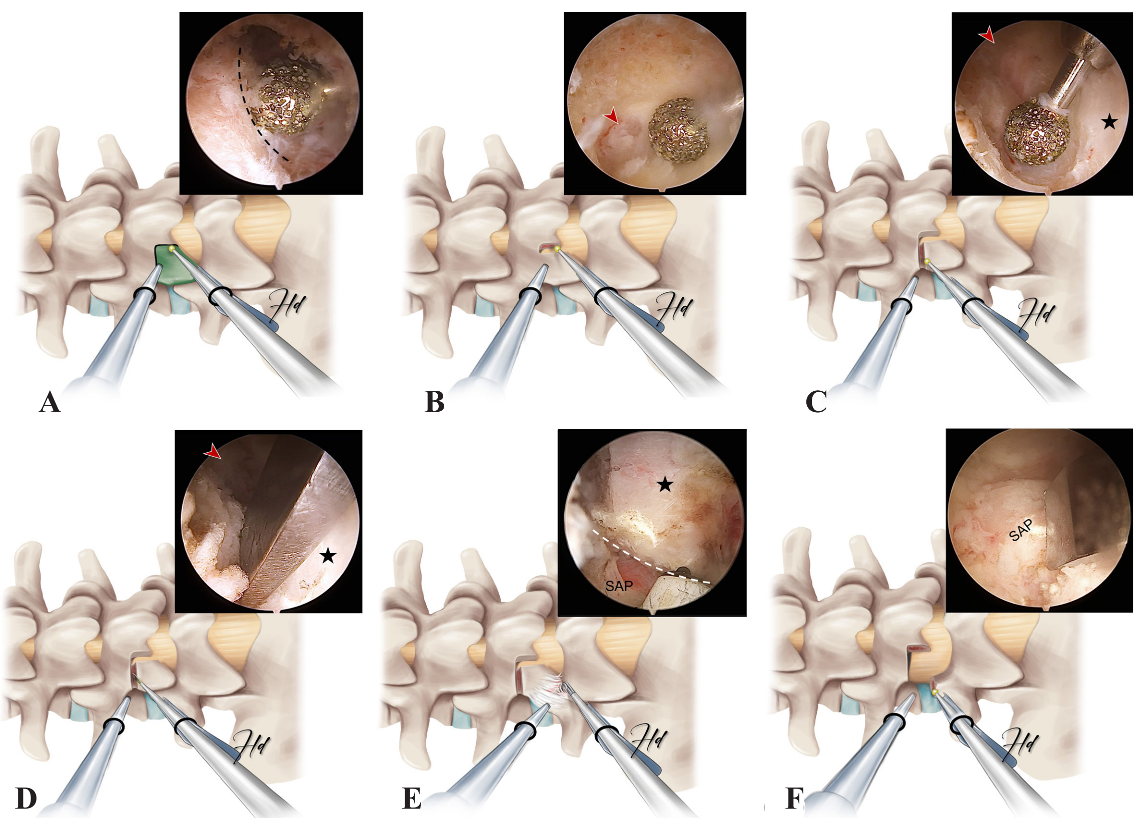


Fig. 2. Illustrations and endoscopic images showing the step-by-step process of laminectomy and the technique for preserving the entire inferior articular process (IAP) as a single intact block. **(A)** Laminectomy begins at the spinous-laminar junction, identifying the lower margin of the cranial lamina (dotted black curve). **(B)** The laminectomy is extended cranially until the upper free margin of the ligamentum flavum is visualized (red arrow). **(C)** Lateral extension is performed to thin the bone of the isthmus toward to the IAP (black star). **(D)** A chisel is used to separate the thinned portion. **(E)** The radiofrequency probe is used to dissect soft tissue around the joint capsule (dotted white curve) to detach the entire IAP as a single block finally. **(F)** The apex of superior articular process (SAP) is thinned with a burr or chisel until the upper border of the pedicle becomes visible.

point strategically positioned near the inferior edge of the cranial lamina, which is the spinous–laminar junction. The optimal working portal was confirmed after achieving true triangulation, as presented in the lateral fluoroscopic view where its dilator aligned parallel to the disc space (Fig. 1A, C).

Unilateral laminectomy and endplate preparation

The scope and semitubular instruments were sequentially inserted into the two pre-established portals, ensuring continuous inflow and outflow of irrigation to maintain a clear view throughout the procedure. A high-speed burr with a 4 mm diamond ball tip was used to perform laminectomy. Burring started at the spinous–laminar junction (Fig. 2A), progressively thinning the lamina cranially until the free edge of the ligamentum flavum (LF) becomes visible (Fig. 2B). From this point, the burr was angled laterally to thin the isthmus bone, angling the burr toward the IAP (Fig. 2C). A small osteotome was used to separate this thinned portion (Fig. 2D). A radiofrequency probe was then utilized to cut through the joint capsule (Fig. 2E). Finally, large forceps were used to remove the entire IAP as a single intact piece (Fig. 3E). To expose the Kambin's triangle widely and ensure adequate working space for endplate preparation and cage insertion, we always burr or chisel the apex of the superior articular process (SAP) until the superior border of the pedicle becomes visible (Fig. 2F). The small bone fragments collected during this step are carefully preserved for later use as autologous bone graft material. A small Penfield was used to detach the LF at the apex of the SAP and establish an opening of adequate size utilizing a Kerrison punch or forceps (Fig. 3A). We consistently retained most of the LF, particularly at the lateral of the spinal canal and the shoulder of the traversing nerve root (TNR), employing

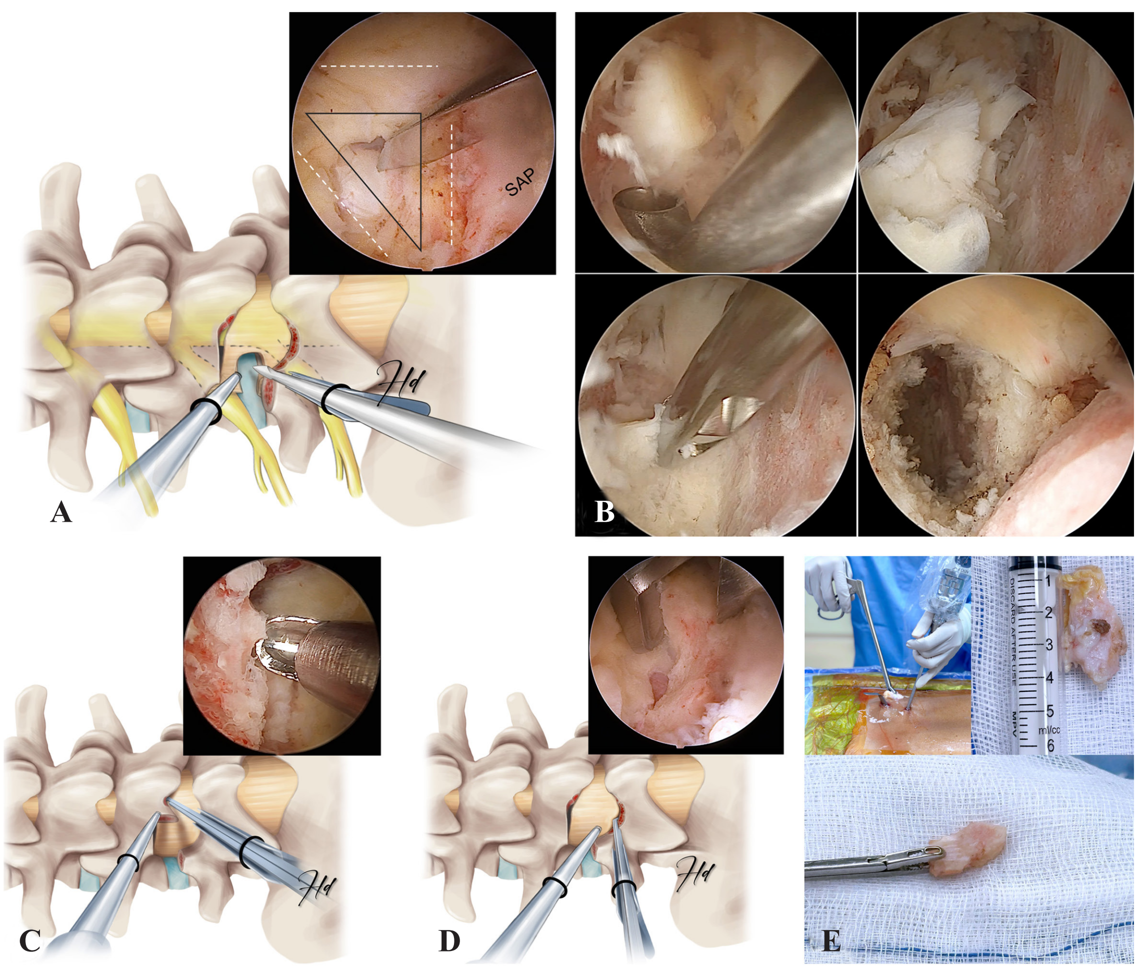


Fig. 3. (A) Detach the ligamentum flavum at the apex of the superior articular process (SAP) and create an opening of adequate size. Exposure and access to Kambin's triangle. **(B)** Endplate preparation steps via endoscopy, using curettes to detach the endplate cartilage and remove the pieces with forceps. **(C, D)** Small bone pieces were harvested from the remaining cranial lamina and the superior border of the caudal lamina for use as autologous bone graft materials. **(E)** The entire inferior articular process is removed as a single intact piece and carefully cleaned of soft tissue.

it as a protective barrier for neural structures. Further, preserving the LF facilitates the safe execution of procedures, such as disc removal, endplate preparation, and cage insertion, without requiring nerve root retractors or assistance from a surgical assistant. Curettes and small chisels with various curved angles are highly beneficial during the endplate preparation process. Care should be taken to minimize bony endplate injury. For the multilayer bone grafting technique, we maximally removed the disc and endplate cartilage anteriorly and laterally to establish sufficient space for inserting the bone graft materials (Fig. 3B).

Multi-layer bone grafting

To increase the amount of autologous bone graft inserted in the fusion space, we carefully utilized a Kerrison to harvest small bone fragments from various sources, a remaining cranial lamina (Fig. 3C), a superior border of the caudal lamina (Fig. 3D), and a portion of the base of the spinous process at the midline. This approach does not utilize a high-speed burr in these areas, unlike during lumbar stenosis decompression. The entire IAP was previously removed and meticulously cleaned of soft tissues, leaving only the bone with an appropriate size for grafting (Fig. 3E). The multilayer bone grafting technique begins by placing approximately 5 mL of fine HA bone (Fig. 4C) mixed with small local fragment autografts at the deepest layer. This was followed by inserting the entire IAP, which served as a barrier to prevent HA bone migration. Finally, a TLIF cage filled with autologous bone was inserted. This stage was performed under direct endoscopic visualization and fluoroscopic imaging to ensure the intended positioning of the bone graft materials (Fig. 4A). Further, the irrigation pressure was reduced throughout this stage to improve control.

Neural decompression and PPSF

The process of neural decompression was continued, ensuring complete decompression of the spinal canal, ipsilateral lateral recess, ipsilateral exiting nerve root (ENR), and ipsilateral TNR as well as the contralateral lateral recess, contralateral ENR, and contralateral TNR. Meticulous hemostasis was achieved using hemostatic materials such as Gelfoam or Floseal. PPSF was performed with the ipsilateral side, the screws are inserted through two previous skin incisions for the working portal and scope portal. The LS was reduced under fluoroscopic guidance by first securing the caudal pedicle screws, then performing reduction by levering and pulling up the cranial vertebra. Finally, the skin was closed and the procedure was completed.

Measurement of the outcomes

Clinical outcomes were assessed using the Visual Analog Scale (VAS) for low back pain and leg pain, along with the Oswestry Disability Index (ODI) for functional impairment. These scores were recorded preoperatively, at discharge, and during follow-up visits at 3 months, 6

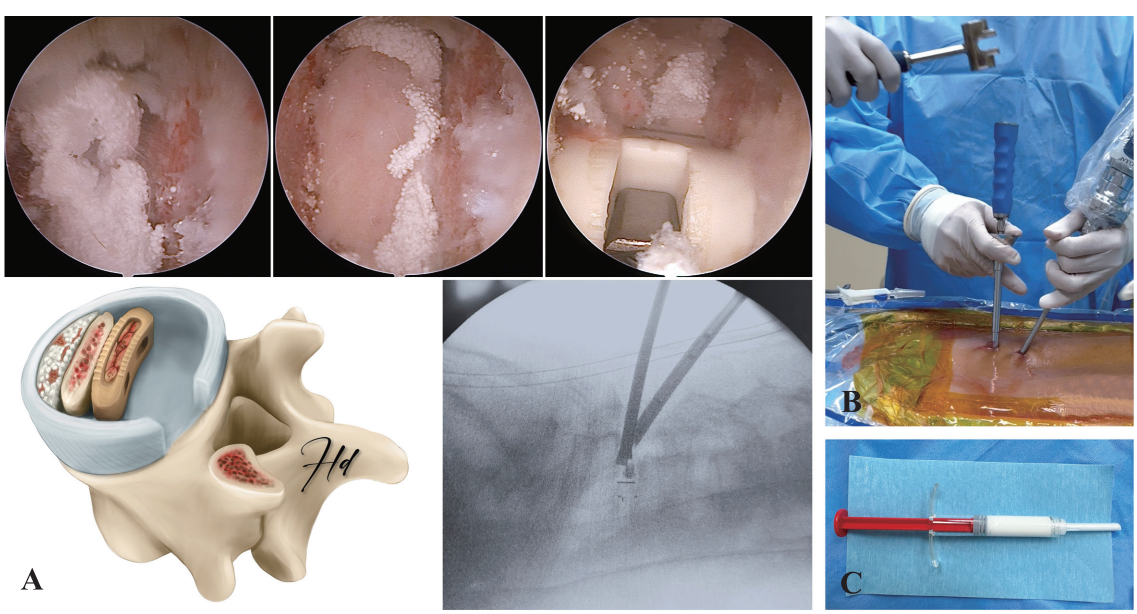


Fig. 4. (A) Steps of the multi-layer bone grafting technique, consisting of 3 layers: hydroxyapatite (HA) bone, the entire inferior articular process, and a transforaminal lumbar interbody fusion cage packed with autologous bone, under fluoroscopic guidance. **(B)** Cage insertion without the use of retraction tools. **(C)** Fine HA bone is used.

months, and the final follow-up. Radiological outcomes were assessed using lumbar spine CT scans performed 6 months postoperatively. The fusion status was identified using the Bridwell grading system, with grades I and II defined as successful fusion. Cage subsidence was measured as >2 mm migration into the endplate on sagittal CT images. The distribution of bridging bone formation was categorized into intracage bridging bone, extracage bridging bone, or a combination of both, based on axial CT images. Independent evaluators, who were blinded to the study design to reduce bias, performed all measurements.

Statistical analysis

Statistical analysis was conducted to assess both clinical and radiological outcomes. Continuous variables, such as VAS and ODI scores, were presented as mean±standard deviation, whereas categorical variables were reported as frequencies and percentages. Paired sample *t*-tests were employed to compare the preoperative and postoperative clinical scores. Subgroup analyses were conducted using chi-square tests for categorical variables, including comparisons between grades I and II LS. A *p*-value of <0.05 indicated statistical significance. All analyses were conducted using the IBM SPSS software ver. 28.0 (IBM Corp., Armonk, NY, USA).

Results

Patient demographics and preoperative characteristics

During the study period, 41 patients underwent BE-LIF for single-level LS. The mean age of the cohort was 58.6±13.8 years (range, 42–76 years), with 68.3% of patients being male (28/41). The mean body mass index was 22.6±4.2 kg/m^2 (range, 18.2–27.1 kg/m^2). Comorbidities, including diabetes mellitus, hypertension, chronic obstructive pulmonary disease, congestive heart failure, and previous cerebral infarction, were observed in 36.6% of patients. Osteoporosis was present in 63.4% of the cohort. Preoperative symptoms included sensory disturbances alone (63.4%) and combined sensory and motor disturbances (36.6%). The affected levels were L4–L5 (58.6%), L5–S1 (34.1%), and L3–L4 (7.3%), with 73.2% of patients classified as grade I LS and 26.8% as grade II LS (Table 1).

Operative parameters and clinical outcomes

The mean operation time for the entire BE-LIF procedure, including PPSF, was 182.8±36.4 minutes (range, 150–240 minutes). The mean intraoperative blood loss was 190.5±81.3 mL, with no cases requiring blood transfusion. The average hospital stay was 7.2±3.6 days (range, 4–10 days), and most patients began ambulation 2 days postoperatively. Clinical outcomes exhibited significant improvement in pain and disability scores. The VAS scores for low back pain decreased from 7.8±0.8 preoperatively to 3.5±2.6 at discharge and 2.1±1.4 at the final follow-up (p<0.001). The VAS scores for leg pain similarly improved from 8.1±1.3 preoperatively to 2.8±2.1 at discharge and 1.9±1.5 at the final follow-up (p<0.001). The ODI scores improved from 50.4±15.4 preoperatively to 16.7±13.2 at discharge and 14.8±10.5 at the final follow-up (p<0.001). Minor complications occurred in two patients (4.9%) due to dural tears, both of which were successfully managed—one with endoscopic repair and the other conservatively. No major complications, such as nerve root injury, pedicle screw issues, or infections, were reported (Tables 2, 3).

Table 1. Patient demographics and preoperative characteristics

Characteristic	Value
Age (yr)	58.6±13.8
Sex	
Male	28 (68.3)
Female	13 (31.7)
Body mass index (kg/m^2)	22.6±4.2
Presence of comorbidities[a)]	15 (36.6)
Presence of osteoporosis	26 (63.4)
Preoperative symptoms	
Sensory disturbances only	26 (63.4)
Combined sensory and motor disturbances	15 (36.6)
Operative levels	
L3–L4	3 (7.3)
L4–L5	24 (58.6)
L5–S1	14 (34.1)
Meyerding classification of spondylolisthesis	
Grade I	30 (73.2)
Grade II	11 (26.8)
Grade III	0
Grade IV	0
Grade V	0

Values are presented as mean±standard deviation or number (%).
[a)]Age-related health disorders in modified 5-item frailty index: diabetes mellitus, hypertension, chronic obstructive pulmonary disease or recent pneumonia, congestive heart failure, and history of cerebral infarction.

Table 2. Clinical outcome

Variable	Preoperative	Postoperative at discharge	Postoperative at last follow-up	*p*-value
Visual Analog Scale score				
Low back pain	7.8±0.8	3.5±2.6	2.1±1.4	<0.001
Leg pain	8.1±1.3	2.8±2.1	1.9±1.5	<0.001
Oswestry Disability Index	50.4±15.4	16.7±13.2	14.8±10.5	<0.001

Values are presented as mean±standard deviation.

Table 3. Perioperative finding

Intraoperative finding	Value
Operation time (min)	182.8±36.4
Intraoperative blood loss (mL)	190.5±81.3
Hospital stay (day)	7.2±3.6
Time to ambulation (day)	2.0±0.5
Complications	
Dural tears	2 (4.9)
Nerve root injury	0
Pedicle screw-related issues	0
Infection	0

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

Table 4. Summary of radiological outcome

Variable	Value	*p*-value
Lumbar lordosis (°)		0.061
Preoperative	42.4±5.9	
Postoperative	43.0±5.8	
Segment lordosis (°)		0.066
Preoperative	18.6±8.4	
Postoperative	24.3±6.7	
Foraminal height (mm)		<0.001
Preoperative	12.6±2.6	
Postoperative	19.2±5.3	
Anterior disc height (mm)		<0.001
Preoperative	8.3±1.15	
Postoperative	8.9±1.23	
Posterior disc height (mm)		<0.001
Preoperative	7.8±1.0	
Postoperative	8.2±1.0	
Fusion rate		
Fusion	34 (82.9)	
Non-fusion	7 (17.1)	
Bridwell grading		
Grade I	10 (24.3)	
Grade II	24 (58.6)	
Grade III	7 (17.1)	
Grade IV	0	
Distribution of bridging bone		
InCBB + ExCBB	20 (48.8)	
Only InCBB	10 (24.4)	
Only ExCBB	4 (9.8)	
Cage subsidence	2 (4.9)	

Values are presented as mean±standard deviation or number (%).
InCBB, intra-cage bridging bone; ExCBB, extra-cage bridging bone.

Radiological outcomes

Six months postoperatively, lumbar spine CT scans exhibited a successful fusion rate of 82.9% (34/41), with fusion grades I in 24.3% and II in 58.6% of patients. Cage subsidence occurred in two patients (4.9%), defined as >2 mm of migration into the endplate, despite not requiring revision surgery. Bridging bone formation was observed in 48.8% of other cases, with both intracage and extracage bridging bone. An additional 24.4% demonstrated intracage bridging bone alone, whereas 9.8% showed extracage bridging bone exclusively. Further, radiological measurements revealed significant improvements in the disc height. The anterior disc height increased from 8.3±1.15 mm preoperatively to 8.9±1.23 mm postoperatively (p<0.001), whereas the posterior disc height improved from 7.8±1.0 to 8.2±1.0 mm (p<0.001). Changes in L1-S1 lumbar and segmental lordosis were not significant; however, the improvement in the foraminal height was statistically significant (Table 4).

Comparison between grades I and II LS

The subgroup analysis revealed no statistically significant differences in the fusion rates between grades I and II LS (p=0.09). However, patients with grade II LS demonstrated a higher proportion of grade II fusion (90.9%) than those with grade I LS (46.7%). Further, the distribution of bridging bone and cage subsidence rates did not significantly differ between the two groups (Table 5).

Table 5. Comparison of radiological outcomes based on spondylolisthesis grading

Characteristic	Grade of lumbar spondylolisthesis		*p*-value
	Grade I (n=30)	Grade II (n=11)	
Fusion rate			
Fusion	23 (76.7)	11 (100.0)	0.09
Non-fusion	7 (23.3)	0	
Bridwell grading			
Grade I	9 (30.0)	1 (9.1)	0.167
Grade II	14 (46.7)	10 (90.9)	0.01*
Grade III	7 (23.3)	0	0.09
Grade IV	0	0	
Distribution of bridging bone			
InCBB + ExCBB	12 (40.0)	8 (72.3)	0.06
Only InCBB	7 (23.3)	3 (27.3)	0.54
Only ExCBB	4 (13.3)	0	0.27
Cage subsidence	2 (6.7)	0	0.53

Values are presented as number (%).
InCBB, intra-cage bridging bone; ExCBB, extra-cage bridging bone.
*$p<0.05$.

Discussion

Endoscopic lumbar interbody fusion (ELIF), including both uniportal lumbar interbody fusion (ULIF) and BE-LIF techniques, has gained significant traction as an effective approach for managing lumbar spine instability [4,7,14,15]. BE-LIF, in particular, has appeared as a popular and reliable method, as supported by several studies from leading surgical centers reporting favorable clinical outcomes [8,10,11,14,16,17]. Our results are congruent with these findings, which demonstrate significant VAS and ODI score improvements and a low complication rate (Tables 2, 3). As a minimally invasive surgery (MIS), BE-LIF provides notable advantages, including reduced soft tissue disruption, which facilitates shorter recovery times, decreased postoperative pain, and lower intraoperative blood loss [4,14-16,18]. This is further evidenced by the absence of cases that require blood transfusion in our study, which may be related to the controlled irrigation pressure used during the procedure, which minimizes venous bleeding. BE-LIF has demonstrated superior outcomes, such as less postoperative pain, earlier ambulation, and shorter hospital stays, compared with traditional TLIF, posterior lumbar interbody fusion (PLIF), or MIS-TLIF [10,18-20]. These results indicate the advantages of ELIF in minimizing paraspinal muscle damage [14]. With a smaller incision and reduced surrounding tissue disruption, ELIF is associated with less surgical trauma compared to traditional techniques. The procedure helps limit muscle injury and inflammation, as indicated by lower C-reactive protein and creatine kinase levels, resulting in faster recovery and better postoperative outcomes. Further, ELIF supports long-term muscle preservation, as reflected in the maximal cross-sectional area of the multifidus muscle, thereby reducing the risk of muscle atrophy and chronic lower back pain. This contributes to improved functional recovery and a lower risk of complications such as failed back surgery syndrome [14].

Moreover, BE-LIF provides superior distinct technical advantages over ULIF, including a wider surgical field, enhanced instrument maneuverability, improved visibility for cage implantation, and shorter operative times, which were all made possible by separating the working and viewing portals [6,7,14,21]. This configuration improves precision, reduces the risk of neural injury, and enables optimal decompression and control of the contralateral structures. This results in a noteworthy point that the operative time for BE-LIF is significantly shorter than that of ULIF [21]. Moreover, the use of a 30° scope further expands the field of view, thereby facilitating safe and effective decompression [22]. We also utilize a low-torque high-speed burr and chisel to excise bony structures, either in small fragments or *en-bloc*, to minimize bleeding risks, particularly in patients with osteoporosis. By resecting the apex of the SAP to the pedicle's border, we ensured broad Kambin's triangle exposure and gained access to the disc space through the caudal endplate, which is a region with minimal risk of nerve root injury [23,24]. Further, we advocate for partially preserving the LF during the initial stages of endplate preparation and bone grafting, using it as a protective barrier to mitigate the effects of irrigation pressure on the dura. The LF is only fully respected after graft placement to achieve complete decompression of both the exiting and TNRs bilaterally. The contralateral IAP was resected in cases where the disc height is <5 mm to facilitate reduction more effectively as an alternative to the routine over-the-top decompression technique. These technical refinements underscore the safety, efficacy, and versatility of BE-LIF as a MIS for LS.

Successful fusion is considered a pivotal factor in the surgical management of LS in addition to achieving effective neural decompression [1,2,21,25]. A fusion success rate of 82.9% was observed based on the postoperative lumbar spine CT scans conducted in 6 months. No significant differences in the CT imaging parameters for assessing fusion were identified between patients with grades 1 and 2 LS (Tables 4, 5). Few previous studies have used uniform CT assessments at a single postoperative time point to evaluate this outcome [8,10,11]. Most of these studies involved a mean follow-up period of >12 months, demonstrating consistently high fusion effectiveness of the BE-LIF technique, accounting for >90%, not different from that of MIS-TLIF or conventional PLIF [10,18-20], and even higher than ULIF [21]. The promising preliminary findings from our study using the BE-LIF multilayer bone grafting technique further validate this result. However, a longer follow-up period is required to assess the stability of the bridging bone interbody formed on early postoperative lumbar spine CT scans. Several factors have influenced the fusion efficacy of LIF procedures, including the volume of the bone graft in the disc space, the size of the cage footprint, the type of graft material used, and the integrity of the bony endplate [13,21,25,26].

Different strategies have been proposed to increase the amount of bone graft within the disc space [8,9,11]. Pao [8] indicated that due to the limited capacity of the cage to accommodate the bone graft, the volume of graft material outside the cage plays a more crucial role. The use of double TLIF cages, interspersed with bone grafts, improved the overall graft volume, and maximized its retention within the disc space. The authors revealed a high fusion rate of 93.3% while discussing alternative cost-effective cage material options. In our approach, we used a combination of HA bone and autograft in small fragments, the entire IAP, and autograft that was placed within the cage to maximize the bone graft volume within the disc space by alternating in multiple layers (Fig. 4A). HA facilitates osteogenesis using the properties of autografts rather than relying solely on fragmented autografts [13,26]. The IAP was utilized as an *en-bloc* bone structure to prevent smaller bone fragment migration, thereby ensuring optimal placement and stability. In the literature, fusion has been well established as a complex biological process, fundamentally a competition between graft resorption and new bone formation within the graft, ultimately associating the two adjacent vertebral bodies [13,27]. Further, restoring and preserving the disc space height are crucial objectives of interbody fusion [2,27]. In the BE-LIF multilayer bone grafting technique, the structural integrity of the carefully prepared IAP, which was achieved by removing soft tissues while preserving the cortical bone, provides temporary disc height maintenance in combination with a conventional TLIF cage. This stability enables the deeper layers of the bone graft and the packed graft inside the cage to facilitate solid bony bridging. On axial CT imaging, we revealed that the proportion of cases demonstrating the formation of intracage and extracage bridging bone was 48.8%. The use of autograft material, HA bone, and only one traditional TLIF cage, as predominantly performed in open surgery or MIS-TLIF, does not increase treatment costs and remains feasible in limited-resource settings.

Increasing the size of the cage footprint or the direct contact area between the fusion materials and the endplate surface also plays a crucial role in promoting successful fusion [8,13,21,27]. Its position and orientation within the disc space play an equally important role in addition to the size of the cage. Compared to ULIF, the cage in BE-LIF can be placed transversely under biportal endoscopic visualization, which is more consistent with mechanical principles [21]. Heo et al. [9] proposed the use of an OLIF cage as a strategy to optimize this parameter. However, this approach requires an additional lateral incision distant from the midline. In the BE-LIF multi-layer bone grafting technique, the entire IAP is used as a secondary cage-like structure to maximize the contact area, which adheres to the constraints of limited resources. The application of a local morselized bone autograft in TLIF has exhibited cost-effectiveness while maintaining high fusion rates [28]. This efficiency is primarily related to the reduced reliance on allografts and the corresponding decrease in the total bone graft expenditure. Furthermore, positioning the IAP as a rigid anterior component within the vertebral body enables primary cage placement, which appears to be positioned from the middle of the vertebral body toward the posterior region. This facilitates the restoration of the posterior disc height, which indirectly expands the neural foramen and improves the sustained decompression of the ENR (Fig. 5C). Recently, a growing consensus indicated that lumbar lordosis restoration in lumbar fusion surgery is increasingly emphasized due to its effect on improvements in pain and function; however, the use of expandable cages has been proposed as a means to achieve greater lordosis by lengthening the anterior column while maintaining a small insertion trajectory, thereby making them suitable for MISS techniques, including endoscopic approaches [29]. However, regarding lumbar and segment lordosis improvements after single-level TLIF, both expandable and non-expandable cages have demonstrated similar outcomes [29]. Using the BE-LIF multi-layer bone grafting technique, we observed that both anterior and posterior disc height, particularly foraminal height, improved statistically significantly, whereas the postoperative increase in lumbar lordosis was not significant (Tables 4, 5). This appears beneficial

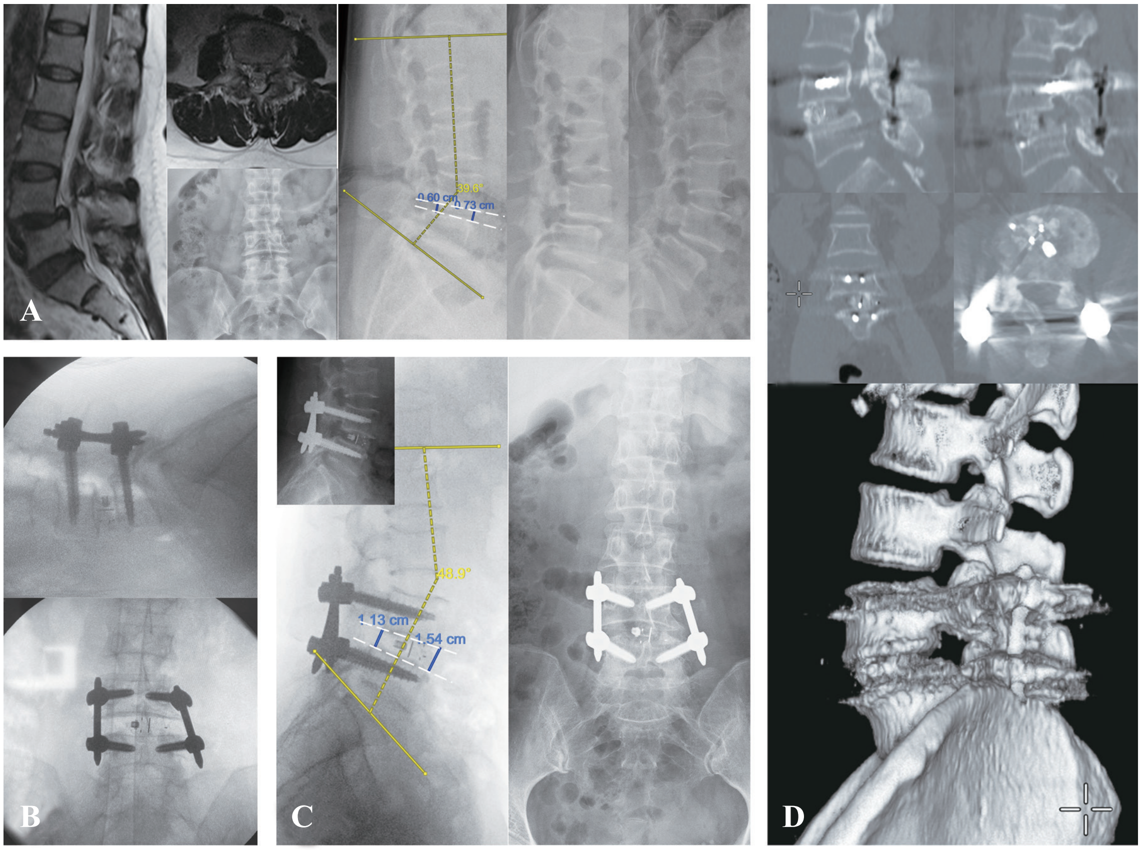


Fig. 5. (A) Preoperative magnetic resonance imaging and X-ray images of a male patient with spondylolisthesis due to isthmic at the L4–5 level. **(B)** Intraoperative fluoroscopic image. **(C)** Postoperative X-ray at 3 months showing restoration of disc height and reduction of spondylolisthesis. **(D)** Postoperative lumbar spine computed tomography images at 6 months demonstrating the formation of bridging bone both intra-cage and extra-cage.

in achieving effective indirect decompression, especially in cases of low-grade LS.

Meticulous preparation of the grafting site before placing the bone materials is a crucial factor in improving bone fusion efficacy and reducing cage subsidence incidence [8,13]. Cage subsidence causes posterior cage migration and loss of lumbar lordosis, potentially resulting in poor clinical outcomes [8,30]. One of the advantages of endoscopic spine surgery is the ability of the endoscope to access and directly visualize anatomical structures with high magnification [4,7,14]. Adjusting the angle to achieve a clear view of the surgical field is considerably quicker and more flexible with a 30° scope than with a microscope, where the cylindrical structure of the tubular retractor constrained illumination direction [7,14]. This improved visualization enables maximum disc material and endplate cartilage removal while preventing bony endplate injury. We consistently ensure thorough disc material and endplate cartilage removal, particularly in the anterior and lateral regions, to establish sufficient space for bone graft material insertion. Further, this step facilitates loosening the connection between the adjacent vertebral bodies, thereby optimizing the conditions for reduction during the PPSF procedure. Furthermore, we detach the endplate in fragments using curettes and small chisels with various curved angles instead of relying on conventional serial disc shavers. This approach improves precision and minimizes the risk of endplate damage. Moreover, the entire cage insertion process in BE-LIF is performed under simultaneous direct endoscopic visualization and fluoroscopic imaging, preventing the blind implantation of the cage using only fluoroscopic imaging as in the ULIF procedure [7,8,11]. This approach significantly minimizes the risk of endplate damage, thereby improving the fusion rate of BE-LIF compared with ULIF [21].

In summary, the preliminary results of BE-LIF application utilizing the multi-layer bone grafting technique indicate BE-LIF as an effective and safe method for improving clinical outcomes and achieving satisfactory fusion in LS management. However, several limitations of this study should be acknowledged. First, as a retrospective review with a small sample size and short follow-up period, the study is subject to potential biases that may have affected data collection and analysis. The relatively short follow-up duration limits the ability to evaluate long-term fusion rates, potential late-onset complications, and clinical improvement durability. Future studies with extended follow-up would be warranted to identify whether these initial positive outcomes are sustained over time. Second, this is a single-center study in which the same surgeon performed all procedures; thus, the results lack generalizability and randomization, particularly regarding the low complication rate observed. This limitation indicates the need for caution when interpreting the safety of this procedure. The single-surgeon design may introduce an element of performance bias while ensuring procedural consistency, as surgical expertise and familiarity with the technique could affect both operative efficiency and complication rates. Multicenter studies that involved multiple surgeons with varying experience levels would provide a more comprehensive assessment of this technique's reproducibility. Generally, the BE-LIF is technically demanding, requiring a steep learning curve to master and perform safely. Moreover, we involved no control group in comparison with other fusion techniques. This omission originates from the study's primary focus on detailing the step-by-step methodology of the BE-LIF with the multi-layer bone grafting technique and highlighting its promising outcomes, particularly in resource-constrained settings with limited access to advanced fusion materials. Despite these limitations, the positive results of this study indicate its potential applicability to similar healthcare institutions.

Conclusions

The BE-LIF technique using multi-layer bone grafting, which combines HA bone grafts with autologous bone harvested from the preserved IAP as a structural bone block, supplemented by a TLIF cage, has exhibited both safety and efficacy. BE-LIF approach not only improves neurological symptom relief and facilitates solid bone fusion but also introduces a cost-effective and feasible solution for healthcare settings with limited access to expensive fusion materials such as dual TLIF, OLIF, or titanium cages. Considering the advantages of the BESS methodology and optimizing the use of locally available resources, this technique broadens the applicability of minimally invasive spinal fusion surgery across diverse clinical environments.

Key Points

- This study details the step-by-step procedure of the biportal endoscopic lumbar interbody fusion technique using multilayer bone grafting materials.
- The multi-layer bone grafting technique uses the entire inferior articular process as a bone graft material, providing a cost-effective alternative to high-cost options such as dual transforaminal lumbar interbody fusion (TLIF), oblique lumbar interbody fusion, or titanium cages. This approach not only prevents hydroxyapatite bone graft migration in the water environment during endoscopy but also provides a stable structure with a large contact area to facilitate bone fusion alongside the traditional TLIF cage.
- This technique is particularly suitable for resource-limited medical settings. The results indicate the potential broader application of biportal endoscopic spine surgery in healthcare facilities with comparable constraints while maintaining effective treatment outcomes.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Acknowledgments

The data used in this research were acquired from a public resource.

ORCID

Tran Vu Hoang Duong: https://orcid.org/0009-0001-7809-7864; Pham Anh Tuan: https://orcid.org/0000-0002-0659-3279; Huynh Van Vu: https://orcid.org/0009-0002-7363-3274; Chu Van Lam: https://orcid.org/0009-0001-3013-5649; Le Tan Linh: https://orcid.org/0009-0008-3500-6919; Phan Duy: https://orcid.org/0000-0001-9779-174X; Wongthawat Liawrungrueang: https://orcid.org/0000-0002-4491-6569

Author Contributions

Conceptualization: TVHD, PAT, HVV, CVL, LTL, PD. Methodology: TVHD, PAT, HVV, CVL, LTL, PD. Data curation: TVHD, PAT, HVV, CVL, LTL, PD. Formal analysis: TVHD, PAT, HVV, CVL, LTL, PD. Visualization: TVHD, PAT, HVV, CVL, LTL, PD. Project administration: TVHD. Writing–original draft preparation: TVHD, PAT, HVV, CVL, LTL, PD, WL. Writing–review and editing: TVHD, WL. Supervision: TVHD, PAT, WL. Final approval of the manuscript: all authors.

References

1. Mobbs RJ, Phan K, Malham G, Seex K, Rao PJ. Lumbar interbody fusion: techniques, indications and comparison of interbody fusion options including PLIF, TLIF, MI-TLIF, OLIF/ATP, LLIF and ALIF. J Spine Surg 2015;1:2-18.
2. Meng B, Bunch J, Burton D, Wang J. Lumbar interbody fusion: recent advances in surgical techniques and bone healing strategies. Eur Spine J 2021;30:22-33.
3. Verma R, Virk S, Qureshi S. Interbody fusions in the lumbar spine: a review. HSS J 2020;16:162-7.
4. Wu PH, Kavishwar RA, Kim HS. A narrative review of current and future of unilateral biportal endoscopic (UBE) transforaminal lumbar interbody fusion. Semin Spine Surg 2024;36:101084.
5. Park DY, Upfill-Brown A, Curtin N, et al. Clinical outcomes and complications after biportal endoscopic spine surgery: a comprehensive systematic review and meta-analysis of 3673 cases. Eur Spine J 2023;32:2637-46.
6. Kwon H, Park JY. The role and future of endoscopic spine surgery: a narrative review. Neurospine 2023;20:43-55.
7. Ahn Y, Youn MS, Heo DH. Endoscopic transforaminal lumbar interbody fusion: a comprehensive review. Expert Rev Med Devices 2019;16:373-80.
8. Pao JL. Biportal endoscopic transforaminal lumbar interbody fusion using double cages: surgical techniques and treatment outcomes. Neurospine 2023;20:80-91.
9. Heo DH, Eum JH, Jo JY, Chung H. Modified far lateral endoscopic transforaminal lumbar interbody fusion using a biportal endoscopic approach: technical report and preliminary results. Acta Neurochir (Wien) 2021;163:1205-9.
10. Park MK, Park SA, Son SK, Park WW, Choi SH. Clinical and radiological outcomes of unilateral biportal endoscopic lumbar interbody fusion (ULIF) compared with conventional posterior lumbar interbody fusion (PLIF): 1-year follow-up. Neurosurg Rev 2019;42:753-61.
11. Zhu C, Liang J, Pan H, Zhang W. Far lateral lumbar interbody fusion with unilateral pedicle screw fixation and double traversing cages using a biportal endoscopic technique. Acta Neurochir (Wien) 2023;165:2165-9.
12. Chen Y, Xu C, Wu Y, Shi J, Chen R. Application of RhBMP-2 in percutaneous endoscopic posterior lumbar interbody fusion. BMC Surg 2024;24:376.
13. Park HJ, Shin JI, You KH, et al. Biportal endoscopic transforaminal lumbar interbody fusion: how to improve fusion rate? Int J Spine Surg 2024;18:582-8.
14. Pholprajug P, Kotheeranurak V, Liu Y, Kim JS. The endoscopic lumbar interbody fusion: a narrative review, and future perspective. Neurospine 2023;20:1224-45.
15. Kang MS, Heo DH, Kim HB, Chung HT. Biportal endoscopic technique for transforaminal lumbar interbody fusion: review of current research. Int J Spine Surg 2021;15(suppl 3):S84-92.
16. Heo DH, Lee DC, Kim HS, Park CK, Chung H. Clinical results and complications of endoscopic lumbar interbody fusion for lumbar degenerative disease: a meta-analysis. World Neurosurg 2021;145:396-404.
17. Park MK, Son SK. Biportal endoscopic lumbar interbody fusion: review of current evidence and the literature. J Minim Invasive Spine Surg Tech 2021;6(Suppl 1):S171-8.
18. Lin GX, Yao ZK, Zhang X, Chen CM, Rui G, Hu BS. Evaluation of the outcomes of biportal endoscopic lumbar interbody fusion compared with conventional fusion operations: a systematic review and meta-analysis. World Neurosurg 2022;160:55-66.
19. Kang MS, You KH, Choi JY, Heo DH, Chung HJ, Park HJ. Minimally invasive transforaminal lumbar interbody fusion using the biportal endoscopic techniques versus microscopic tubular technique. Spine J 2021;21:2066-77.
20. Luan H, Peng C, Liu K, Song X. Comparing the efficacy of unilateral biportal endoscopic transforaminal lumbar interbody fusion and minimally invasive transforaminal lumbar interbody fusion in lumbar degenerative diseases: a systematic review and meta-analysis. J Orthop Surg Res 2023;18:888.
21. Ding Y, Chen H, Wu G, Xie T, Zhu L, Wang X. Comparison of efficacy and safety between unilateral biportal endoscopic transforaminal lumbar interbody fusion versus uniportal endoscopic transforaminal lumbar interbody fusion for the treatment of lumbar degenerative diseases: a systematic review and meta-analysis. BMC Musculoskelet Disord 2024;25:1037.
22. Kim N, Jung SB. Percutaneous unilateral biportal endoscopic spine surgery using a 30-degree arthroscope in patients with severe lumbar spinal stenosis: a technical note. Clin Spine Surg 2019;32:324-9.
23. Quillo-Olvera J, Quillo-Resendiz J, Quillo-Olvera D, Barrera-Arreola M, Kim JS. Ten-step biportal endoscopic transforaminal lumbar interbody fusion under computed tomography-based intraoperative navigation: technical report and preliminary outcomes in Mexico. Oper Neurosurg (Hagerstown) 2020;19:608-18.
24. Lau ET, Wu PH. Technical note on unilateral biportal lumbar endoscopic interbody fusion. Surg Tech Dev 2022;11:71-89.
25. Kim E, Brennan M, Margabandu P, et al. Bone grafting options for single-level TLIF: so many options, what is the evidence? Int J Spine Surg 2023;17(S3):S53-60.
26. Yoo JS, Min SH, Yoon SH. Fusion rate according to mixture ratio and volumes of bone graft in minimally invasive transforaminal lumbar interbody fusion: minimum 2-year follow-up. Eur J Orthop Surg Traumatol 2015;25 Suppl 1:S183-9.
27. Johnson SE, Michalopoulos GD, Flanigan PM, et al. Interbody cages versus structural bone grafts in lumbar arthrod-

esis: a systematic review and meta-analysis. J Neurosurg Spine 2024;41:188-98.
28. Halalmeh DR, Perez-Cruet MJ. Use of local morselized bone autograft in minimally invasive transforaminal lumbar interbody fusion: cost analysis. World Neurosurg 2021;146:e544-54.
29. Yee TJ, Joseph JR, Terman SW, Park P. Expandable vs static cages in transforaminal lumbar interbody fusion: radiographic comparison of segmental and lumbar sagittal angles. Neurosurgery 2017;81:69-74.
30. Oh KW, Lee JH, Lee JH, Lee DY, Shim HJ. The correlation between cage subsidence, bone mineral density, and clinical results in posterior lumbar interbody fusion. Clin Spine Surg 2017;30:E683-9.