Acta Neurochirurgica (2023) 165:1435–1443
https://doi.org/10.1007/s00701-023-05605-7

TECHNICAL NOTE

Biportal endoscopic extraforaminal lumbar interbody fusion using a 3D-printed porous titanium cage with large footprints: technical note and preliminary results

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Received: 21 March 2023 / Accepted: 18 April 2023 / Published online: 28 April 2023

Abstract

Purpose The aim of this study was to introduce biportal endoscopic extraforaminal lumbar interbody fusion (BE-EFLIF), which involves insertion of a cage through a more lateral side as compared to the conventional corridor of transforaminal lumbar interbody fusion. We described the advantages and surgical steps of 3D-printed porous titanium cage with large footprints insertion through multi-portal approach, and preliminary results of this technique.

Methods This retrospective study included 12 consecutive patients who underwent BE-EFLIF for symptomatic single-level lumbar degenerative disease. Clinical outcomes, including a visual analog scale (VAS) for back and leg pain and the Oswestry disability index (ODI), were collected at preoperative months 1 and 3, and 6 months postoperatively. In addition, perioperative data and radiographic parameters were analyzed.

Results The mean patient age, follow-up period, operation time, and volume of surgical drainage were 68.3 ± 8.4 years, 7.6 ± 2.8 months, 188.3 ± 42.4 min, 92.5 ± 49.6 mL, respectively. There were no transfusion cases. All patients showed significant improvement in VAS and ODI postoperatively, and these were maintained for 6 months after surgery ($P < 0.001$). The anterior and posterior disc heights significantly increased after surgery ($P < 0.001$), and the cage was ideally positioned in all patients. There were no incidences of early cage subsidence or other complications.

Conclusions BE-EFLIF using a 3D-printed porous titanium cage with large footprints is a feasible option for minimally invasive lumbar interbody fusion. This technique is expected to reduce the risk of cage subsidence and improve the fusion rate.

Keywords Biportal endoscopic spinal surgery · Extraforaminal lumbar interbody fusion · Three-dimensional printed porous titanium cage · Large footprints cage · Lumbar degenerative disease

Background

In lumbar degenerative diseases with mechanical instability or the need to correct for underlying deformity or extensive decompression, lumbar interbody fusion (LIF) has been routinely performed [4, 12, 14, 17, 22]. The posterior LIF (PLIF) approach is the most traditional method that enables sufficient direct central canal decompression but has the high risk of iatrogenic paraspinal muscle injury. The anterior LIF approach has the advantages of using a more lordotic cage with a larger footprint and reduced risk of paraspinal muscle injury but has the disadvantage that only indirect decompression is possible. In transforaminal lumbar interbody fusion (TLIF), in the direct decompression of pathologies causing foraminal stenosis, such as degeneration of the facet joint in the hypertrophied superior articular process (SAP), endplate osteophyte, or foraminal disc, herniation is possible, and back muscle injury has been reduced through a unilateral approach [10, 16, 25].

Conventional open TLIF was first devised by Harms and Rolinger in 1982, and minimally invasive TLIF (MI-TLIF) using a tubular retractor was later implemented by Foley

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et al. in 2003 [3, 6]. Recently, biportal endoscopy has been emerging as a minimally invasive technique, and biportal endoscopic TLIF (BE-TLIF) is also now being performed. This is a technique performing facetectomy and cage insertion using the same corridor as the previous MI-TLIF technique through biportal endoscopy, and shows similar clinical outcomes compared to MI-TLIF [2, 5, 7, 9, 11, 26]. This technique shows a similar fusion rate as MI-TLIF, but there is some concern regarding the washout of graft material due to intraoperative continuous irrigation. Park et al. reported fewer cases of definite fusion and more cases of probable fusion in BE-TLIF [18]. Therefore, a method to improve the fusion rate in BE-TLIF is required. In this study we describe a novel biportal endoscopic extraforaminal lumbar interbody fusion (BE-EFLIF) technique using 3D-printed large cage through a more lateral side than the conventional corridor of TLIF. In addition, we describe the advantages of a 3D-printed porous titanium cage with large footprints and a multi-portal approach, and our preliminary results with this technique.

Methods

Study design and patient characteristics

This study was approved by the Institutional Review Board of Hallym University Kangnam Sacred Heart Hospital (IRB No: 2022-10-017). This retrospective medical chart review was conducted on 12 patients who underwent BE-EFLIF between January and June 2022 in a single hospital. The inclusion criteria were as follows: (1) age 50–80 years; (2) refractory pain that was not controlled by conservative treatment for more than 3 months; and (3) a single level of lumbar degenerative disease requiring fusion. Exclusion criteria were as follows: (1) multi-level disease; (2) history of previous lumbar surgery at the same level; (3) other pathological conditions, such as infection or tumor; and (4) patients who had not been followed up with for more than 6 months.

Perioperative data, clinical outcomes, and radiographic parameters

Demographic data included age, sex, body mass index, and bone mineral density. Perioperative data, such as operation level, direction, hospital stay, operation time, estimated blood loss, and amount of surgical drainage, were collected. Clinical outcomes, including a visual analog scale (VAS) for back and leg pain and the Oswestry Disability Index (ODI) were assessed preoperatively and at 1, 3, and 6 months after surgery. Radiographic parameters, such as lumbar lordosis (LL), segmental lordosis, anterior and posterior disc height, pelvic tilt, sacral slope, pelvic incidence (PI), and PI-LL mismatch, were measured. In addition, cage positioning and early subsidence were analyzed on postoperative radiographs. As in previous studies, a cage position within the anterior 1/3 of disc space was considered ideal [19], and cage subsidence was defined as greater than a 2-mm loss in height, and early subsidence was defined as occurring within the first 6 weeks postoperatively [21].

Surgical procedure

Anesthesia and surgical position

The patient was placed in the prone position on the radiolucent Jackson spinal table under general anesthesia. The surgical level was confirmed under the C-arm imaging. Figure 1 shows the overall operation room setting.

Posterior decompression

Central canal decompression was performed first, if necessary. If not, facetectomy was performed immediately, and sufficient disc space for cage insertion was secured.

Central canal decompression Central canal decompression, contralateral facetectomy, and facet joint release were performed with the ipsilateral posterior approach. The M portal was made just superior to the target disc space level, and the M′ portal was made at an interval of 1.5–2 cm in the caudal direction (Fig. 2).

Direct decompression of the central canal was performed through an ipsilateral posterior approach. Ipsilateral hemilaminotomy was performed using a chisel and kerrison rongeur. The base of the spinous process was sufficiently undercut using a burr; thereafter, central decompression was performed through ligamentum flavectomy. Decompression was continued until the contralateral facet was reached, and contralateral facet release was performed to increase segmental mobility to prevent subsidence during cage insertion (Fig. 3, Video clip 1).

Facetectomy and foraminotomy Facetectomy and foraminotomy could be performed using the far lateral approach. First, two incisions were made 2 cm lateral to the pedicle lateral margin of the target level, and these ports were called the P+2 (L) and P+2 (R) ports. If central canal decompression was not required, an additional M portal was made as a portal for endoscope insertion during cage insertion later (Fig. 2). After confirming the transverse process (TP) of the lower vertebra through the far lateral approach, the facet joint was confirmed while proceeding to the medial side from the TP. The facet joint capsule was peeled off using a bipolar radiofrequency thermo-controlled ablator. The

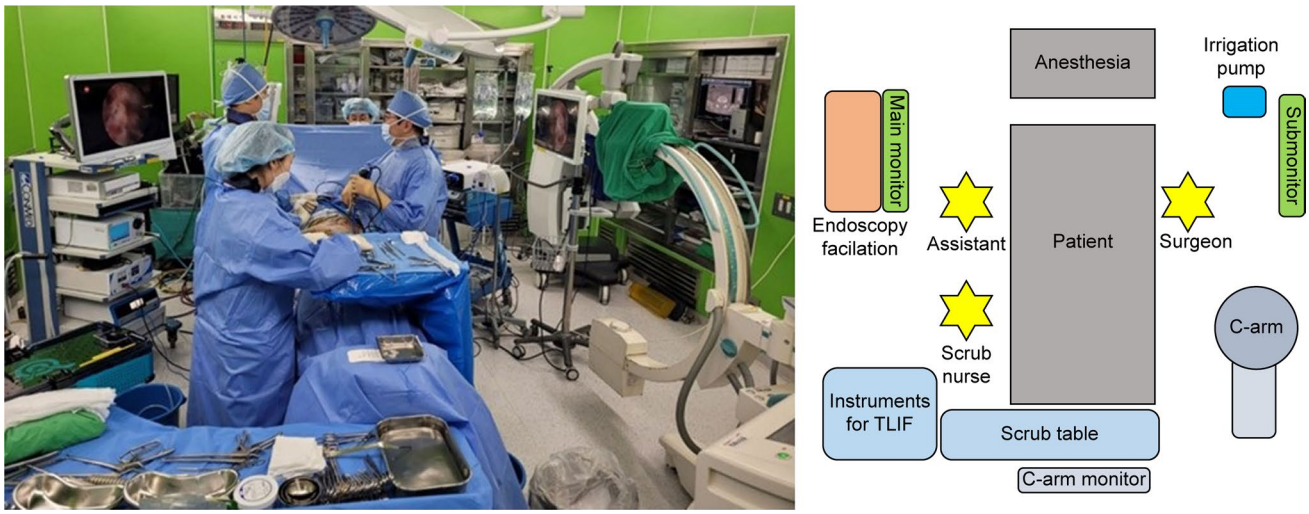

Fig. 1 Operation room setup and schematic diagram for BE-EFLIF. BE-EFLIF biportal endoscopic extraforaminal lumbar interbody fusion, TLIF transforaminal lumbar interbody fusion

SAP was first removed using a small-diameter high-speed diamond burr and chisel, and after confirming the isthmus, the inferior articular process was removed. At this time, the use of the burr was reduced as much as possible, and the maximum amount of autobone was gained using a chisel. Thereafter, ligamentum flavectomy was performed, and the Kambin's triangle was confirmed. Foraminotomy was then performed while removing the medial portion of the TP, residual portion of the SAP, and lateral portion of the isthmus located around the exiting nerve using a Kerrison ronguer (Fig. 4, Video clip 2).

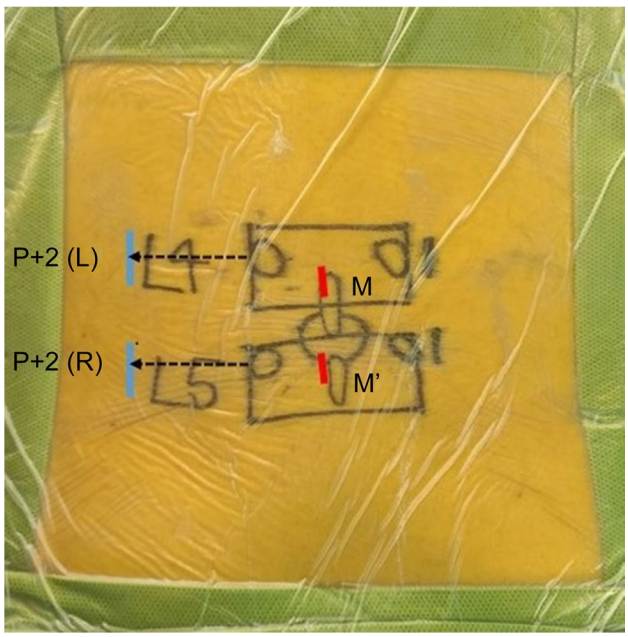

Fig. 2 Surgical incisions for BE-EFLIF using multiportal approach. P + 2 ports mean that it is made 2 cm lateral to the pedicle lateral margin, and are used for facetectomy and foraminotomy. Based on when a right-handed surgeon performs a left side approach, the port on the left used as a viewing port is called P + 2 (L) port, and the port on the right used as a working port is called P + 2 (R) port. Additional M and M′ ports are made to perform central canal decompression if it is necessary. These ports are also used for endoscope and root retractor during cage insertion.
BE-EFLIF, biportal endoscopic extraforaminal lumbar interbody fusion

Disc space preparation and bone graft

Disc space preparation through the Kambin's triangle was performed through a far lateral approach. In order to make an entry site on the far lateral side and insert a large cage, a safe margin of at least 20 mm from the lateral margin of the traversing root had to be secured (Fig. 5). First, annulotomy was performed using an Indian knife. A nucleus fragmentectomy was performed by inserting a disc reamer into the intervertebral disc space and rotating it serially. The cartilaginous endplate and disc material were removed using pituitary forceps. Thereafter, by changing the viewing port to the M or M′ port, meticulous endplate preparation was performed using an angled curette while observing the endplate to the corner. After completion of endplate preparation, disc height was increased with minimal damage to the bony endplate using a serial trial implant. Bone graft materials were placed in the anterior disc space through a specially designed funnel-shaped bone graft device.

Cage insertion and cage positioning

In this technique, a single 3D-printed porous titanium cage (PANTHER SPINAL CAGE TLIF, MANTIZ Co. Ltd.,

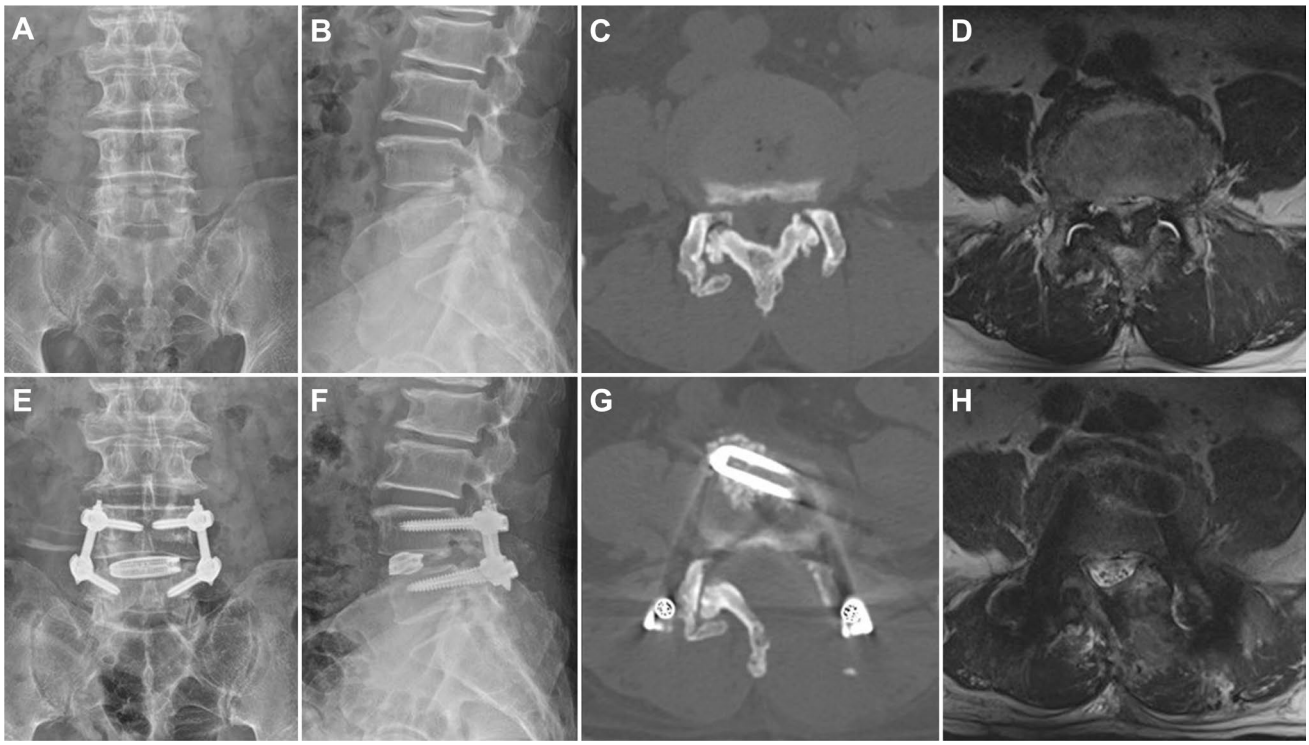

Fig. 3 A case of BE-EFLIF that required central canal decompression. A 69-year-old woman underwent surgery for low back pain and bilateral leg pain that had lasted 5 years. **a**, **b** Preoperative radiographic finding of degenerative spondylolisthesis L4 on L5. **c** Bilateral facet joint arthritis and multiple bony spurs in the CT axial image. **d** Severe central canal stenosis in the T2 axial MRI image. **e**, **f** In the postoperative radiograph, the cage is properly positioned. Spondylolisthesis reduction and disc height restoration have been obtained. **g**, **h** In the postoperative CT and MRI axial images, well-decompression can be confirmed. BE-EFLIF biportal endoscopic extraforaminal lumbar interbody fusion, CT computed tomography, MRI magnetic resonance imaging

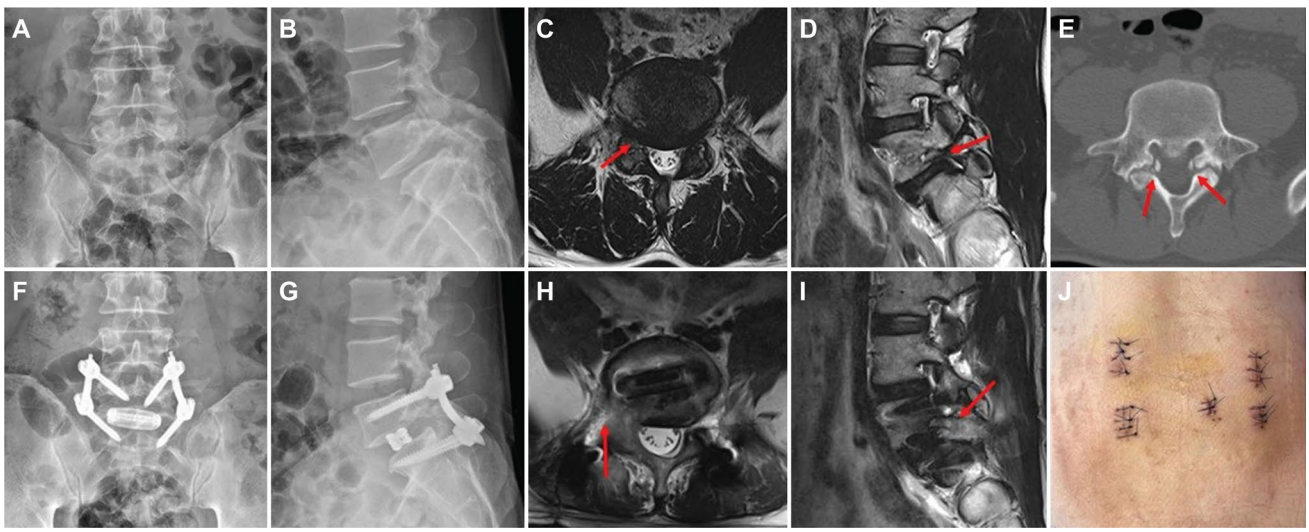

Fig. 4 A case of BE-EFLIF that did not require central canal decompression. A 45-year-old man who suffered from right leg pain for 4 years with motor weakness which appeared 3 months prior to presentation. **a**, **b** Preoperative radiographic finding of spondylolytic spondylolisthesis L5 on S1. **c**, **d** In the preoperative MRI, central canal stenosis is not severe, but right neural foraminal stenosis is confirmed. **e** Bilateral neural foraminal bony spurs in the preoperative CT axial image. **f**, **g** Postoperative radiograph. **h**, **i** Postoperative MRI shows well-decompressed right L5–S1 foraminal area. BE-EFLIF, biportal endoscopic extraforaminal lumbar interbody fusion. CT computed tomography, MRI magnetic resonance imaging

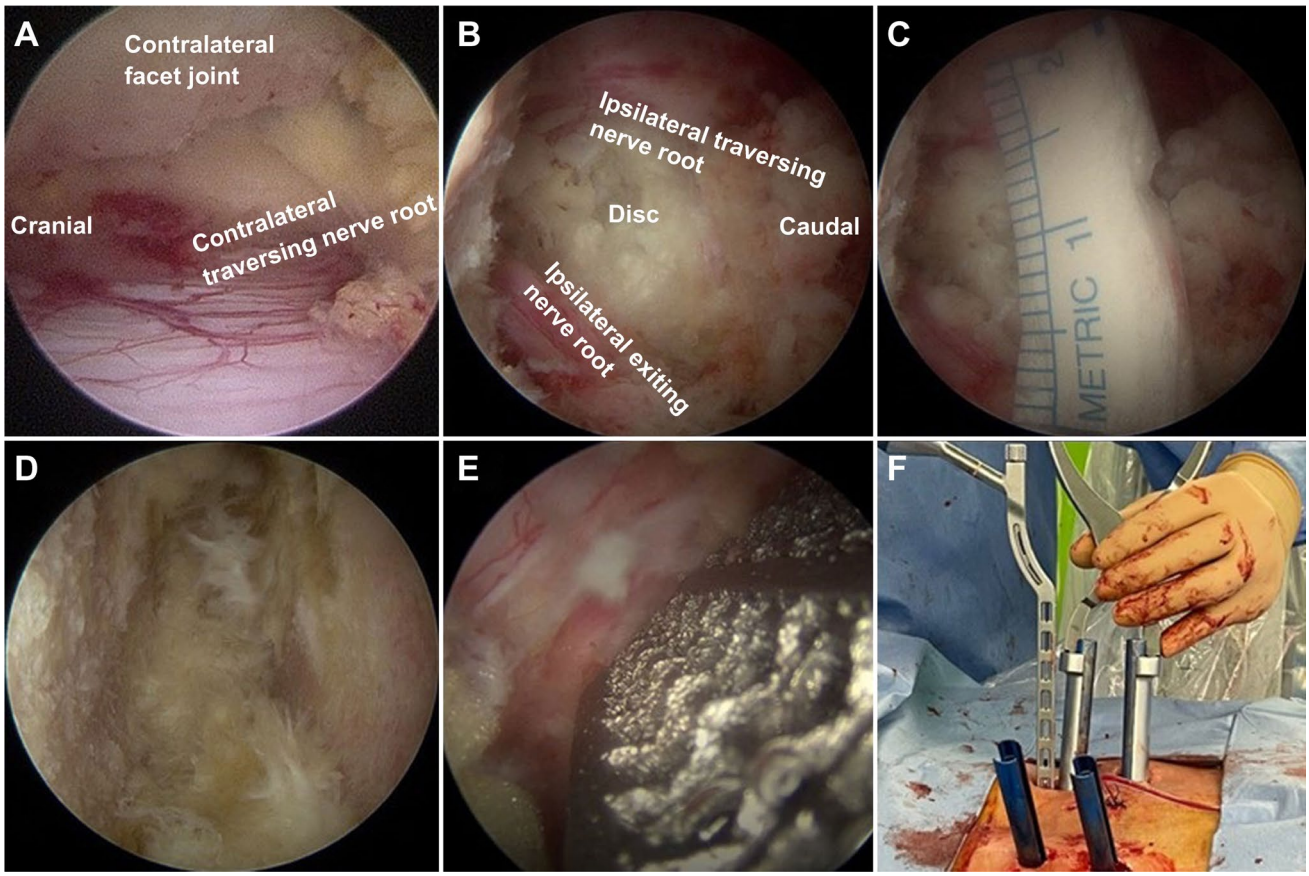

Fig. 5 Overall step for BE-EFLIF. **a** Intraoperative endoscopic finding of contralateral decompression and facet joint release. **b** Kambin's triangle. **c** A safe margin of at least 20 mm from the lateral margin of the traversing root for large cage insertion. **d** Meticulous endplate preparation is performed under multiportal endoscopic approach. **e** Cage insertion. **f** Maximal lordortic curve is obtained by using a compressor after bending the rod. BE-EFLIF biportal endoscopic extraforaminal lumbar interbody fusion

Daegu, South Korea) was used. The length and width of the cage were 40 and 13 mm, respectively, and the appropriate height was selected during surgery. After filling the cage with bone graft material, the exiting and traversing root were protected using a root retractor, and cage insertion was performed. First, the cage was inserted to some extent through a far lateral approach, then the cage impactor was inserted into the M′ port, and thereafter, the cage insertion was continued so that the cage was positioned parallel to the coronal plane (Video clip 3). The C-arm was used to confirm that the cage was positioned on the anterior one-third of the vertebral body, and the apophyseal ring was bilaterally covered. Hemostasis was performed under endoscopic visualization, and a surgical drainage was inserted through the M′ port.

Percutaneous screw fixation

Percutaneous pedicle screw fixation (LOSPA IS SPINAL SYSTEM, Corentec Co., Ltd., Cheonan-si, Chungcheongnam-do, South Korea) was performed through the P+2 (L) and (R) ports and by adding two incisions on the contralateral side. When inserting the rod, the maximal lordortic curve was obtained using a compressor after bending the rod (Fig. 5).

Statistical analysis

The Wilcoxon signed rank test was used to evaluate the clinical and radiographic outcomes. A P value less than or equal to 0.05 was considered statistically significant. All statistical analyses were performed using SPSS software (version 26.0; SPSS, Inc., Chicago, IL, USA).

Results

A total of 12 patients, 8 men and 4 women, were included in the study. The mean age of the patients was 68.3 ± 8.4 years, and mean follow-up period was 7.6 ± 2.8 months. The direction of approach was determined according to the patient's lesion; there were 8 cases of L4–5 level and 4 cases of L5–S1 level. Mean operation time was 188.3 ± 42.4 min,

Table 1 Demographic data

Variable	Value
Patients (n)	12
Age (years)	68.3 ± 8.4
Sex	
Male	8 (66.7%)
Female	4 (33.3%)
Body mass index (m/kg2)	24.6 ± 1.9
Bone mineral density (T-score)	−1.1 ± 1.0
Direction	
Right	8 (66.7%)
Left	4 (33.3%)
Operation level	
L4–5	8 (66.7%)
L5–S1	4 (33.3%)
Operation time (min)	168.3 ± 42.4
Estimated blood loss (mL)	92.5 ± 49.6
Surgical drainage (mL)	155.2 ± 44.1
Hospital stay (day)	7.0 ± 3.3
Follow-up period (month)	7.6 ± 2.8

Values are presented as mean ± standard deviation

mean amount of surgical drainage was 155.2 ± 44.1 mL, and there were no transfusion cases (Table 1). All patients showed significant improvement in VAS and ODI postoperatively, and these were maintained for 6 months after surgery (Fig. 6). VAS_Back improved from 6.5 ± 1.8 preoperatively to 3.5 ± 1.1 at 1 month postoperatively ($P = 0.002$), 2.6 ± 0.6 at 3 months postoperatively ($P = 0.002$), and 1.4 ± 0.9 at 6 months postoperatively ($P = 0.002$). VAS_Leg improved from 7.2 ± 1.1 preoperatively to 3.1 ± 1.3 at 1 month postoperatively ($P = 0.002$), 2.1 ± 1.1 at 3 months postoperatively ($P = 0.002$), and 1.5 ± 1.2 at 6 months postoperatively ($P = 0.002$). The ODI improved from 54.2 ± 11.6 preoperatively to 40.3 ± 14.5 at 1 month postoperatively ($P = 0.006$), 28.7 ± 14.9 at 3 months postoperatively ($P = 0.002$), and 21.4 ± 9.4 at 6 months postoperatively ($P = 0.002$). In the radiographic parameters, the anterior disc height (13.0–17.1, $P = 0.003$) and posterior disc height (7.8–10.7, $P = 0.013$) significantly increased after surgery (Table 2). In postoperative radiography, the cage was ideally positioned in all patients, and there were no cases of early cage subsidence. As for other complications, a small-sized dural tear of less than 1 cm occurred in one case, and it was recovered with TachoComb (CSL Behring GmbH, Marburg, Germany) application. There were no other complications, such as symptomatic hematoma, superficial and deep surgical site infection, or incomplete decompression.

Discussion

In this study, BE-EFLIF showed good clinical and radiographic outcomes for up to 6 months after surgery, early cage subsidence did not occur, and the cage was ideally placed in all patients. It has been mentioned in previous studies that the quality of endplate preparation is important to prevent pseudoarthrosis and increase the fusion rate [23]. Proper removal of the disc material and cartilaginous endplate to expose the bleeding endplate is the most important factor in increasing the fusion rate and preventing cage subsidence [15]. In the case of BE-EFLIF, endplate preparation was performed using real-time endoscopic visualization, and it was possible to delicately remove only the cartilaginous endplate from various angles and magnified view by changing the position of the endoscope using a multi-port. In

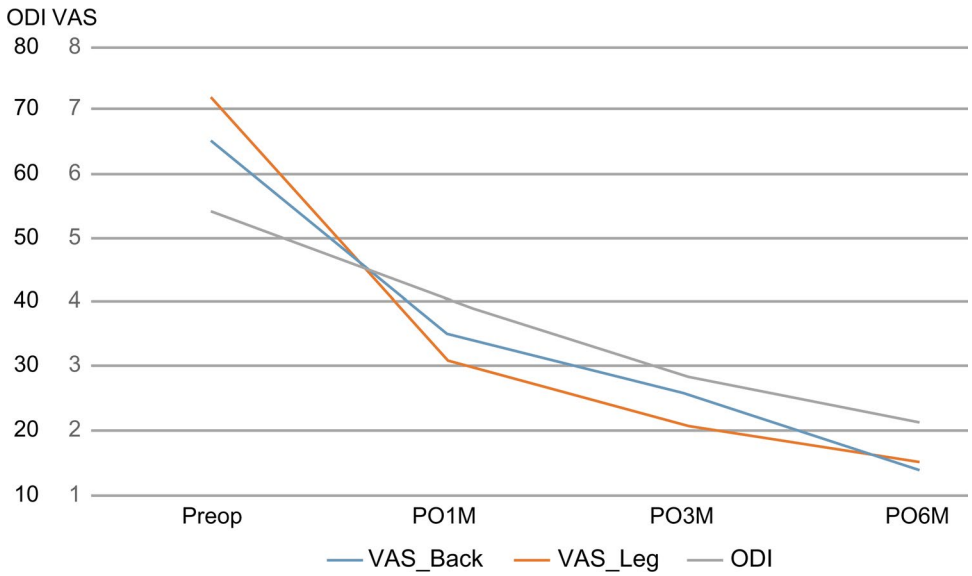

Fig. 6 Clinical outcomes of BE-EFLIF. ODI Oswestry disability index, VAS visual analog scale

Table 2 Radiographic data

	Preoperative	Postoperative 6 months	Difference	*P* value
Segmental lordosis (°)	15.3 ± 5.7	15.7 ± 4.4	0.4 ± 2.7	0.722
Lumbar lordosis (°)	39.6 ± 12.4	39.8 ± 11.4	0.1 ± 5.7	0.790
Anterior disc height (mm)	13.0 ± 4.1	17.1 ± 2.4	4.0 ± 2.6	0.003
Posterior disc height (mm)	7.8 ± 2.2	10.7 ± 2.1	2.9 ± 2.4	0.013
Pelvic tilt (°)	13.8 ± 5.9	14.7 ± 6.3	0.8 ± 2.8	0.350
Sacral slope (°)	33.0 ± 6.6	33.5 ± 5.6	0.4 ± 3.6	0.790
Pelvic incidence (°)	46.9 ± 7.9	48.2 ± 7.7	1.2 ± 2.8	0.131
Pelvic incidence –Lumbar lordosis (°)	7.2 ± 9.1	8.4 ± 9.3	1.2 ± 2.8	0.859

Values are presented as mean ± standard deviation. Statistical significance was set at $P < 0.05$

addition, through the extraforaminal approach, a cage with larger footprints than that used previously in the MI-TLIF technique could be inserted, which is believed to increase the fusion rate.

BE-EFLIF has advantages over the existing BE-TLIF by using a multi-portal approach. First, through the ipsilateral posterior approach, more autobone was obtained while performing direct central canal decompression and intraoperative cage subsidence could be reduced by performing contralateral side facet release. As segmental mobility was increased through this procedure, bony endplate injury could be reduced during cage insertion. Also, in the case of right-handed surgeons, when the operation is performed on the right side, the direction of cage insertion and the intervertebral disc coincide, so cage insertion is easy. However, if the operation is performed on the left side, since the cage is inserted in the opposite direction to the intervertebral disc, there is the risk of endplate damage, and it is difficult to place the cage in ideal position. In this case, by placing the endoscope on the medial side ports and using the cranial ports as working portals, the cage could be inserted more safely while viewing the direction of cage insertion, and this could be used as a passageway for surgical drainage.

In this technique, we used a 3D-printed porous titanium cage. It is known that the early subsidence rate of titanium cages was higher than that of a polyetheretherketone (PEEK) cages [1, 24]. However, the incidence of cage subsidence was lower in the case of 3D-printed porous titanium cages compared to PEEK cages [8, 13]. In BE-EFLIF, intraoperative and early postoperative cage subsidence did not occur, and it is thought that the use of a 3D-printed titanium cage prevented pseudoarthrosis. We are planning a follow-up study on the comparison of subsidence rates between 3D-printed porous titanium and PEEK cages in BE-EFLIF.

A great feature of the anterior LIF approach is the ability to use cages with a larger footprint. According to a biomechanical study on types of cages in lateral LIF showed that wider and larger cages had greater biomechanical stability [20]. In addition, since the endplate is known to be more rigid in the peripheral region called the epiphyseal ring relative the vertebral body central region, it is important to position the cage firmly on the bilateral epiphyseal ring using a large footprint cage [27]. Although such a large cage is difficult to use in a conventional posterior LIF approach, our technique allows the usage of a large cage through the extraforaminal corridor. Through this minimally invasive approach, this approach can obtain sufficient mechanical support even if the autobone is small and some fusion material is washed out due to the continuous irrigation of biportal endoscopy.

BE-EFLIF has similar indications as the conventional posterior LIF approach, such as 1- or 2-level LIF for degenerative spondylolisthesis, isthmic spondylolisthesis (grade 2 or less), and spinal stenosis with instability. The technique is superior for vertical foraminal stenosis accompanied by severe discovertebral degeneration, residual foraminal stenosis after decompressive laminectomy, and degenerative or isthmic spondylolisthesis (grade 2 or less) with or without central canal stenosis. However, as a limitation of BE-EFLIF, the surgeon must first become skilled in biportal endoscopy and overcome the learning curve for BE-TLIF before attempting this procedure. In addition, since the far lateral and the ipsilateral posterior

approaches are performed together using a multi-port, the operation may take a long time.

Conclusion

BE-EFLIF is a feasible option for minimally invasive LIF. By using a multi-portal approach, direct central decompression and contralateral facet release is also possible and the cage is inserted more safely. In addition, a higher fusion rate is expected by inserting a 3D-printed porous titanium cage with large footprints. Therefore, BE-EFLIF is expected to achieve good clinical and radiographic outcomes with minimal invasiveness when performed under appropriate indications.

Abbreviations *TLIF*: Transforaminal lumbar interbody fusion; *MI-TLIF*: Minimally invasive transforaminal lumbar interbody fusion; *BE-TLIF*: Biportal endoscopic transforaminal lumbar interbody fusion; *BE-EFLIF*: Biportal endoscopic extraforaminal lumbar interbody fusion; *VAS*: Visual analog scale; *ODI*: Oswestry disability index; *LIF*: Lumbar interbody fusion; *PLIF*: Posterior lumbar interbody fusion; *SAP*: Superior articular process; *LL*: Lumbar lordosis; *PI*: Pelvic incidence; *TP*: Transverse process; *PEEK*: Polyetheretherketone

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00701-023-05605-7.

Acknowledgements We would like to thank Editage (www.editage.co.kr) for English language editing.

Author contribution KHY: data curation, writing—original draft preparation, funding; HJP: conceptualization, ;
JYH, MSK: writing—review and editing.

Funding This research was supported by the Hallym University Research Fund, 2022 (HURF-2022-35).

Data availability The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate This study was approved by the Institutional Review Board of Hallym University Kangnam Sacred Heart Hospital (IRB No: 2022-10-017). Informed consent was not needed because of the retrospective nature of the study.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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