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ORIGINAL ARTICLE

Clinical and radiological outcomes of unilateral biportal endoscopic lumbar interbody fusion (ULIF) compared with conventional posterior lumbar interbody fusion (PLIF): 1-year follow-up

Man-Kyu Park[1] · Soo-An Park[2,3] · Sang-Kyu Son[1] · Weon-Wook Park[2] · Seung-Hyun Choi[2]

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Abstract

This study retrospectively compared clinical and radiological outcomes of unilateral biportal endoscopic lumbar interbody fusion (ULIF) to those of conventional posterior lumbar interbody fusion (PLIF). Seventy-one ULIF (age, 68 ± 8 years) and 70 PLIF (66 ± 9 years) patients for one lumbosacral segment followed more than 1 year were selected. Parameters for surgical techniques (operation time, whether transfused), clinical results [visual analogue scale (VAS) for back and leg pain, Oswestry disability index (ODI)], surgical complications (dural tear, nerve root injury, infection), and radiological results (cage subsidence, screw loosening, fusion) between the two groups were compared. The PLIF group demonstrated a significantly shorter operation time and more transfusions done than the ULIF group. The VAS for leg pain in both groups and for back pain in the ULIF group significantly improved at 1 week, while the VAS for back pain in the PLIF group significantly improved at 1 year. ODI scores improved at 1 year in both groups. Complication rates were not significantly different between groups. Fusion rates with definite and probable grades were not significantly different between groups. However, the ULIF group had significantly ($P = 0.013$) fewer cases of definite fusion and more cases of probable fusion [43 (74.1%) and 15 (25.9%) cases, respectively] than the PLIF group [58 (92.1%) and 5 (7.9%) cases, respectively]. ULIF is less invasive while just as effective as conventional PLIF in improving clinical outcomes and obtaining fusion. However, ULIF has a longer operation time than PLIF and requires further development to improve the fusion grade.

Keywords Unilateral biportal endoscopic lumbar interbody fusion · Posterior lumbar interbody fusion · Clinical outcome · Radiological outcome

Introduction

As an effort to minimize invasiveness, more and more recent spinal surgeries have been performing endoscopically. Spinal endoscopic surgery has advantages, such as less bleeding, shorter hospital stay, smaller wound size, and less tissue injury, when compared with conventional spinal surgeries [3, 5, 15, 16]. However, no difference in long-term clinical results, a narrow working space with limited vision, and a greater learning curve compared with conventional surgeries have been disadvantages of spinal endoscopic surgeries [4, 6, 7].

In addition to endoscopic discectomy, endoscopic decompression and/or fusion are options as well for patients with lumbar spinal stenosis. However, vision is restricted, and the techniques to utilize specific tools for the uniportal system make conventional endoscopy difficult to learn and practice. Lumbar interbody fusion using uniportal endoscopy has another limitation with cage size, because the cage needs to pass through the working cannula [19].

Recently, unilateral biportal endoscopy (UBE) has been introduced in a wide range of spinal decompression [8, 17] and fusion [6] cases. Transforaminal lumbar interbody fusion under UBE guidance (UBE lumbar interbody fusion

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✉ Soo-An Park
sooan.park@gmail.com

[1] Department of Neurosurgery, Parkweonwook Hospital, Busan, South Korea

[2] Department of Orthopaedic Surgery, Parkweonwook Hospital, 4, Gwangan-ro, Suyeong-gu, Busan 48298, South Korea

[3] Department of Orthopaedic Surgery, Chung General Hospital, 76, Sujeong-ro, Sujeong-gu, Seongnam-si, Gyeonggi-do 13316, South Korea

(ULIF)) is done through a working channel made by a small incision, not though the working cannula. For this reason, the working space of ULIF is extensive enough to insert any size of intervertebral cage. However, there have been few clinical reports in the literature on ULIF compared with conventional open techniques.

The objectives of this study were to compare the preliminary clinical and radiological results of ULIF using 1-year follow-up data, compared with those of conventional posterior lumbar interbody fusion (PLIF), and to determine whether this novel lumbar fusion surgery is feasible, even to the novice of spinal endoscopy.

Materials and methods

Patients

Seventy-one patients underwent ULIF by one (SKS) of the authors in the ULIF group, and another 70 patients underwent PLIF by another author (WWP) in the PLIF group. Patients with spinal stenosis, spondylolisthesis, and herniated nucleus pulposus (HNP) to develop neural compression were included in each group (Table 1). Patients who (1) underwent surgeries for one lumbosacral segment during 2016, (2) were followed for at least 1 year after surgery, (3) answered a questionnaire for pain and disability preoperatively and postoperatively, and (4) signed informed consent approved by the institutional review board were retrospectively selected. Each surgeon in each group has at least 10 years of experience in endoscopic and conventional spinal surgeries, respectively.

Surgical techniques of ULIF

Patients were prepared in the prone position under general anesthesia. The fluoroscopic view was aligned by demonstrating clear endplates of the aiming disc at the center. The transverse incision of the endoscopic channel was made proximally, and another transverse incision of the working channel was made distally with the two incisions about 3 cm apart, where the center of each incision was placed at the lateral margin of the proximal and distal pedicles (Fig. 1).

After positioning the endoscope and the retractor through each channel, the initial submuscular working space was made on the laminar surface under endoscopic guidance. After completing laminectomy wide enough to decompress both sides of the surgical segment while maintaining the ligamentum flavum, the inferior articular process of the upper level and the superior articular process of the lower level were resected by multiple osteotomies to collect the autogenous graft materials. Then, the ligamentum flavum was resected to finalize decompression (Online Resource 1).

After exposing the ipsilateral disc, any vessels on the disc surface were coagulated, and annulotomy was made using a radiofrequency probe. The endplate was denuded after discectomy under endoscopic guidance (Online Resource 2). Harvested local bones were inserted with the demineralized bone matrix (DBM) into the disc space, and then, a peek cage filled with additional local bones and DBM was inserted under endoscopic vision with a retractor anchored at the annulotomy site to protect the exposed thecal sac (Fig. 2) (Online Resource 3). After cage insertion, the procedure was completed with pedicle screws applied percutaneously.

Surgical techniques of PLIF

In prone position under general anesthesia, conventional midline incision, dissection, and decompression were performed bilaterally. The bilateral endplates were denuded after annulotomy. Harvested local bones with DBM were inserted before and with cage insertion at each side through the annulotomy window. The procedure was finalized with pedicle screws applied to the surgical segment.

Table 1 Demographic results of two groups

		ULIF ($n = 71$)	*PLIF* ($n = 70$)	*P* ULIF vs. PLIF
Age (years)		68 ± 8	66 ± 9	0.194
Sex [*n* (%)]	Males	26 (36.6)	20 (28.6)	0.308
	Females	45 (63.4)	50 (71.4)	
Follow-up times (months)		17.1 ± 4.9	20.4 ± 7.2	0.061
BMD [*n* (%)]	$T \leq -2.5$	12 (16.9)	13 (18.6)	0.795
Diagnosis [*n* (%)]	Spinal stenosis	7 (9.9)	11 (15.7)	0.579
	Spondylolisthesis	62 (87.3)	57 (81.4)	
	HNP	2 (2.8)	2 (2.9)	
Fusion level [*n* (%)]	L3-4	13 (18.3)	8 (11.4)	0.405
	L4-5	50 (70.4)	56 (80)	
	L5-S1	8 (11.3)	6 (8.6)	

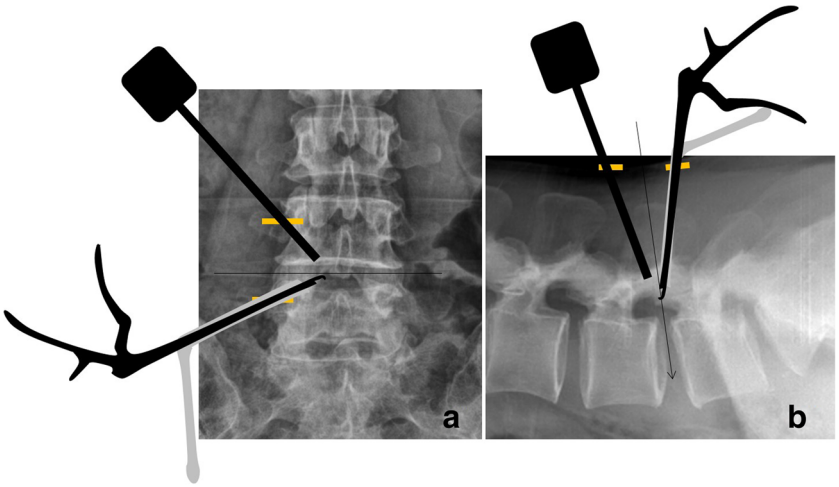

Fig. 1 Two transverse skin incisions (yellow lines) made on the fluoroscopic AP (**a**) and lateral (**b**) views: a scope through the proximal channel and a retractor and a working tool through the distal channel

Experimental setup

This study evaluated four clinical subjects: (1) surgical techniques, (2) clinical results, (3) surgical complications, and (4) radiological results.

The surgical techniques of the two procedures were compared with the operation time [1] and whether the transfusion was done. The clinical results were evaluated by collecting answers to the questionnaire for outcome scores [visual analogue scale (VAS) for back and leg pain and Oswestry disability index (ODI)] preoperatively and a week and a year postoperatively. The surgical complications were evaluated by the incidence of intraoperative dural tear and nerve root injury, re-operation due to the surgical hematoma, and infection within a year.

The radiological results were evaluated by the incidence of cage subsidence, screw loosening, and fusion of surgical segment using 1-year postoperative plain radiographs (AP/lateral views of the lumbar spine). Radiological findings were graded by two spine surgeons using three scales.

In determining fusion grades, each observer classified a case with three grades as definite fusion (grade I) (Fig. 3), non-union (III, IV), or probable fusion (II) (Fig. 4) using Bridwell's fusion grading system [13]. A case with a definite finding was determined by the agreements of two observers. A case with a probable finding was determined by the agreement of two observers or by one observer's decision of definite finding with another's decision of probable (Fig. 5).

Statistical analysis

To analyze the surgical techniques, the operation time of the two groups was compared with the Student's *t* test and the rates of transfusion done were compared with the chi-squared test.

The clinical results (VAS for back and leg pain and ODI) were analyzed using repeated-measures ANOVA with the group (ULIF and PLIF) as an independent variable and the timepoint (preoperative and 1-week and 1-year postoperative timepoints) as a within-subject variable.

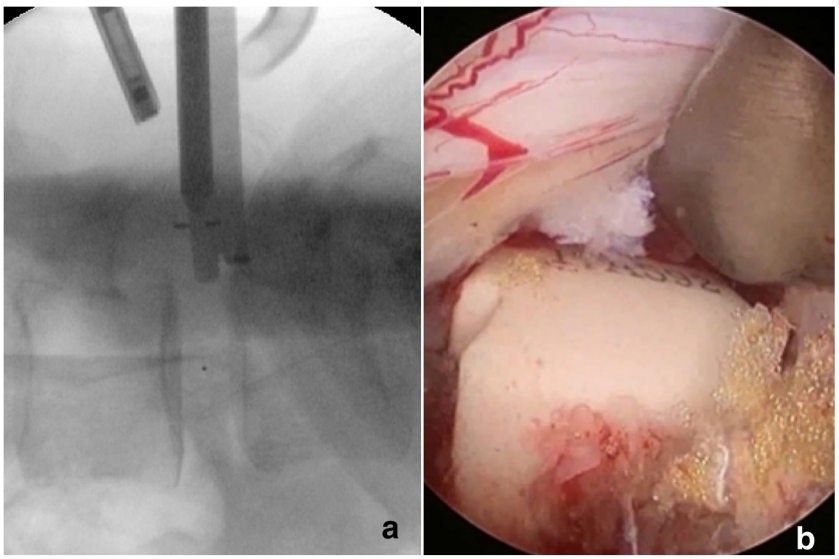

Fig. 2 Impacting the cage into the disc space while protecting thecal sac by the retractor under the fluoroscopic (**a**) and endoscopic surveillance (**b**)

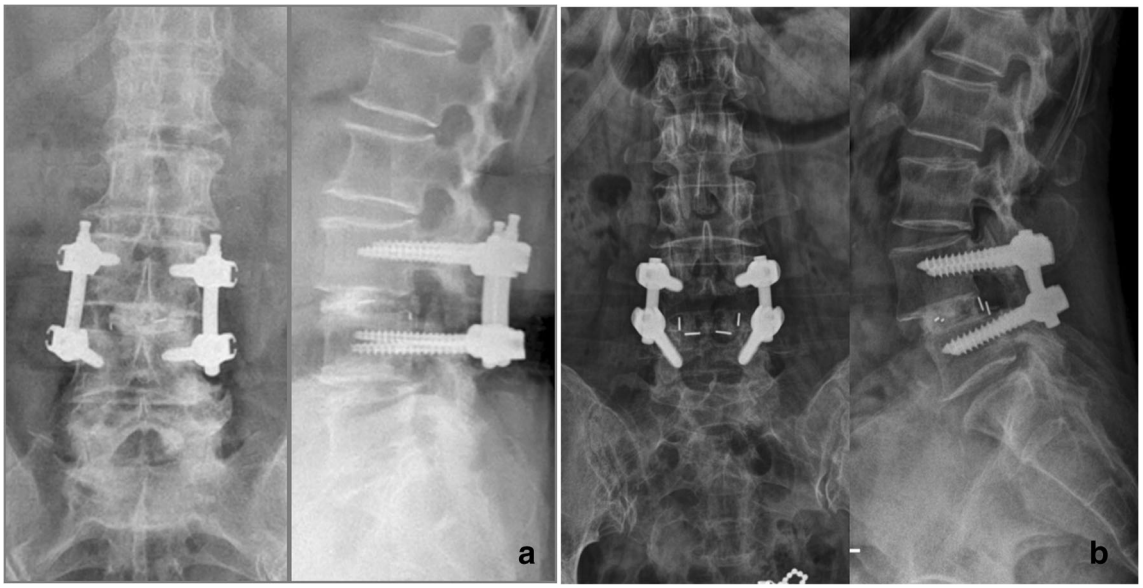

Fig. 3 A case of ULIF graded as definite fusion (**a**) and a case of PLIF as definite fusion (**b**)

The rates of surgical complication (dural tear, nerve root injury, hematoma, and infection) and radiological results (cage subsidence, screw loosening, and fusion) of the two groups were compared with the chi-squared tests. Agreement between two observers for grading radiological results was estimated by the kappa value.

Results

Demographic results

Seventy patients in PLIF and 71 in ULIF groups were not significantly different in age (66 ± 9 years; 68 ± 8 years) and other demographic comparisons (Table 1). For the severity of spondylolisthesis, all patients ($n = 62$, 100%) in the ULIF group were at Meyerding grade I and 49 patients (86%) were at grade I and 8 (14%) were at grade II in the PLIF group. Likewise, patients with spondylolisthesis in two groups were significantly different ($P = 0.002$) in severity of Meyerding grade (Table 2).

For the severity of spinal stenosis, all patients with spinal stenosis and HNP in both groups showed central and/or lateral recess stenosis with severe grade of foraminal stenosis. Severity of foraminal stenosis was graded with three scales (mild, moderate, and severe) [14], and there was no significant difference between the two groups (Table 2). In the ULIF group, ten patients were missed at 1-year follow-up.

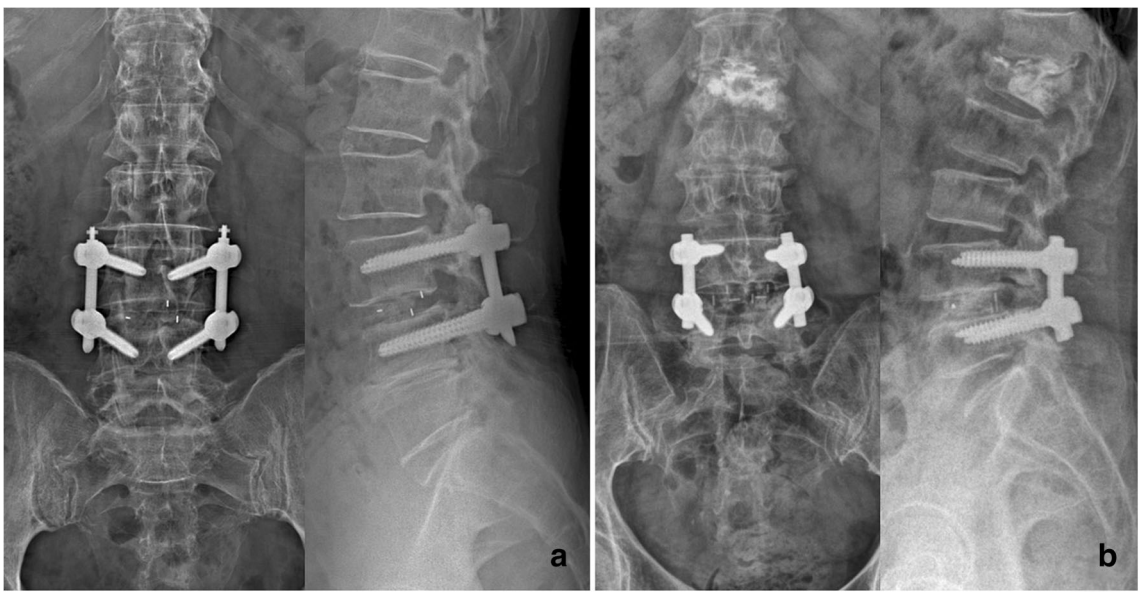

Fig. 4 A case of ULIF graded as probable fusion (**a**) and a case of PLIF as probable fusion (**b**)

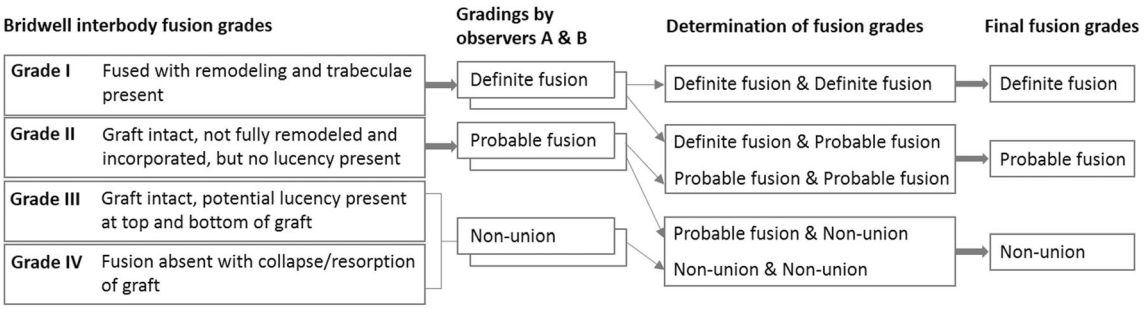

Fig. 5 Two-step grading using two observers' assessments of radiographs with Bridwell interbody fusion grading criteria to determine final fusion grades

Therefore, clinical and radiological results and infection rate were studied with 61 patients.

Surgical techniques

The operation time was significantly longer in the ULIF group (158 min) than in the PLIF group (137 min) ($P < 0.001$). Transfusions were applied in significantly more cases in the PLIF group (20%) than in the ULIF group (no cases) ($P < 0.001$) (Table 3).

Clinical results

The VAS for back pain was not significantly improved at 1 week but was significantly improved at 1 year postoperatively in the PLIF group. However, the VAS for back pain was significantly improved at 1 week in the ULIF group. The VASs for leg pain were improved at 1 week in both groups.

The VAS for back pain was not significantly different between the two groups preoperatively and at 1 year postoperatively. However, postoperative back pain at 1 week was significantly higher in the PLIF group than in the ULIF group.

The ODI scores significantly improved at 1 year postoperatively in both groups (Table 4).

Surgical complications

Rates of any surgical complications were not significantly different between the two groups (Table 5).

Radiological results

Rates of cage subsidence and screw loosening were not significantly different between the two groups when compared cases with definite grade or those with definite and probable grades. Fusion rates with definite and probable grades were not significantly different between the two groups and were ≥ 90% in both groups. However, cases with definite fusion were fewer in the ULIF group (43, 70.5%) than in the PLIF group (58, 82.9%) with a statistical trend ($P = 0.093$), and significantly ($P = 0.013$) fewer cases of definite fusion and more cases of probable fusion were in the ULIF group [43 (74.1%) and 15 (25.9%) cases] than in the PLIF group [58 (92.1%) and 5 (7.9%) cases] in cases with definite or probable fusion grade, respectively (Table 6).

Gradings of cage subsidence (kappa value = 0.369; $P < 0.001$), screw loosening (0.482; $P < 0.001$), and fusion (0.394; $P < 0.001$) were in significant agreement between the two observers to a fair to moderate degree.

Table 2 Grades of spondylolisthesis and foraminal stenosis for patients in two groups

	Grading	ULIF ($n = 71$) N (%)	PLIF ($n = 70$) N (%)	P ULIF vs. PLIF
Spondylolisthesis				0.002*
	1	62 (100)	49 (86)	
	2	0	8 (14)	
	3	0	0	
	4	0	0	
Foraminal stenosis				N/A
	Mild	0	0	
	Moderate	0	0	
	Severe	9 (100)	13 (100)	

*P value with the statistical significance

Table 3 Parameters of the surgical techniques for two groups

	ULIF ($n = 71$)	PLIF ($n = 70$)	P ULIF vs. PLIF
Operation time (min)	158.2 ± 26.7	136.6 ± 21.5	< 0.001*
Transfusion [n (%)]	0 (0)	13 (18.6)	< 0.001*

*P value with the statistical significance

Discussion

Conventional procedures for posterior decompression and fusion have been an effective surgical treatment for lumbar degenerative disease. However, open dissection can denervate the paraspinal muscles leading to an etiology of postoperative back pain and muscle atrophy of the surgical segment [16]. Compared with conventional surgeries, endoscopic spinal surgery has benefits in minimizing muscle damage [5]. Reducing muscle damage particularly to the multifidus muscle is important in maintaining the stability of the spinal segment [4].

In the current study, no cases of transfusion done and less pain in immediate postoperative times in the ULIF group in comparison with the PLIF group indicate that ULIF is a less invasive procedure than conventional PLIF, just as endoscopic spinal decompression is less invasive than conventional decompression.

In a meta-analysis [16] to compare percutaneous endoscopic lumbar discectomy (PELD) and open microdiscectomy (OMD), four out of seven studies demonstrated no significant differences between the two groups in VAS for back pain and ODI score at the last follow-up. Regarding postoperative complications, the rates between PELD (4.7%) and OMD (2.3%) were not significantly different as well.

However, in another meta-analysis [15] to compare the clinical results between minimally invasive discectomy (MID) and microdiscectomy/open discectomy (MD/OD), MID was worse in leg pain than MD/OD at follow-up ranging from 6 months to 2 years, even with differences less than 0.5 point on a 0 to 10 scale. The benefit of MID was in a lower risk of postoperative infection and a shorter duration of hospitalization when compared with MD/OD.

In a study by Lee et al. [12] to evaluate the effects of endoscopic decompression for central to lateral recess stenosis using five studies with more than a 6-month follow-up, the overall scores of VAS for back and leg pain and ODI improved and exceeded the criteria for a minimal clinically important difference. Likewise, incomplete decompression concerned in endoscopic discectomy has been overcome with the evolution of instruments and surgical techniques in recent endoscopic decompression for lumbar spinal stenosis [8, 11, 17]. Moreover, recent spinal endoscopy procedures have been performed not just for decompression but for fusion [6, 19].

Symptom improvement in back pain, leg pain, and ODI at the last follow-up for at least 1 year and a low complication rate in the current ULIF group were not statistically different in comparison with the PLIF group, which indicates that ULIF is as effective as PLIF in decompression and stabilization.

However, a longer operation time, no cases of spondylolisthesis more severe than grade II, and a blind space made from skin to the endoscopic field during cage insertion are probably limitations of current ULIF.

The mean operation time was longer in the ULIF group (158 min) than in the PLIF group (137 min) and even longer than endoscopic fusion surgery in a previous study (114 min) [18]. Surgical procedures through a limited working space with one hand while another hand holds the endoscope, working under water while maintaining the flow, endoscopic surveillance of endplate preparation,

Table 4 Clinical outcome scores for two groups

		N	PRO Mean (SD)	PO (1w) Mean (SD)	PO (1y) Mean (SD)	P PRO vs. PO (1w)	P PO (1w) vs. PO (1y)	P PRO vs. PO (1y)
ULIF	VAS(BP)	61	6.0 (1.5)	3.8 (1.0)	3.1 (0.8)	< 0.001*	< 0.001*	< 0.001*
	VAS(LP)	61	6.6 (1.3)	3.6 (1.3)	3.6 (1.0)	< 0.001*	0.813	< 0.001*
	ODI	61	61.9 (8.2)		32.7 (5.6)			< 0.001*
PLIF	VAS(BP)	70	5.4 (2)	5.2 (1.1)	3.4 (1.4)	0.571	< 0.001*	< 0.001*
	VAS(LP)	70	7.0 (1.7)	3.3 (1.1)	3.3 (1.4)	< 0.001	1.0	< 0.001*
	ODI	70	55.7 (12.1)		29.2 (10.1)			< 0.001*
ULIF vs. PLIF			P	P	P			
	VAS(BP)		0.050	< 0.001*	0.165			
	VAS(LP)		0.063	0.104	0.152			
	ODI		0.001*		0.012*			

PRO preoperative timepoint, *PO (1w)* 1-week postoperative timepoint, *PO (1y)* 1-year postoperative timepoint, *VAS(BP)* visual analogue scale for back pain, *VAS(LP)* visual analogue scale for leg pain, *ODI* Oswestry disability index

*P value with the statistical significance

Table 5 Surgical complications for two groups

Complications	ULIF ($n = 71$) N (%)	PLIF ($n = 70$) N (%)	P ULIF vs. PLIF
Dural tear	3 (4.2)	2 (2.9)	0.660
Nerve root injury	0 (0)	1 (1.4)	0.312
Hematoma	1 (1.4)	1 (1.4)	0.992
Infection	1 (1.4)	2 (2.9)	0.551

and percutaneous pedicle screw fixation may be factors that increase the operation time for ULIF. However, minimally invasive procedures under a clearly magnified view and familiar surgical procedures under a familiar surgical field even to a novice of spinal endoscopy may deserve more time and could be benefits of current ULIF.

When performing lumbar interbody fusion using the uniportal endoscopic system, the cage should be small enough to pass the working cannula [9, 19]. However, the cage in ULIF is not limited in size, because the cage passes through a working channel. Although a blind space is made during cage insertion from the skin to the endoscopic field, a retractor designed to securely protect the thecal sac has made no issues regarding nerve injury for patients in the ULIF group.

As for difficulties associated with ULIF techniques, we suggest unfamiliar anatomical structures in the endoscopic surgical field during the first few procedures, including encountering uncontrolled bleeding and dural tear under water. To establish a proper orientation of the endoscopic surgical field, verifying anatomical structures under a C-arm fluoroscopic view is helpful.

Table 6 Radiological outcomes for two groups

Radiological outcomes	ULIF ($n = 61$) N (%)	PLIF ($n = 70$) N (%)	P ULIF vs. PLIF
Definite and probable grades			
Cage subsidence	5 (8.2)	4 (5.7)	0.733
Screw loosening	3 (4.9)	3 (4.3)	1.0
Bony fusion	58 (95.1)	63 (90.0)	0.337
Definite or probable grade			
Cage subsidence			1.0
Probable grade	4 (80)	4 (100)	
Definite grade	1 (20)	0 (0)	
Screw loosening			1.0
Probable grade	1 (33.3)	2 (66.7)	
Definite grade	2 (66.7)	1 (33.3)	
Bony fusion			0.013*
Probable grade	15 (25.9)	5 (7.9)	
Definite grade	43 (74.1)	58 (92.1)	
Definite grade			
Cage subsidence	1 (1.6)	0 (0)	0.282
Screw loosening	1 (1.6)	2 (2.9)	0.642
Bony fusion	43 (70.5)	58 (82.9)	0.093**

*P value with the statistical significance

**P value with the statistical trend

Bleeding frequently occurred during these endoscopic procedures, like the conventional open spinal procedures, especially when resecting ligamentum flavum and superior articular process. Epidural bleeding can be coagulated using the radiofrequency probe at the lowest power, and uncontrolled epidural bleeding even after coagulation can be controlled by packing hemostatic materials such as gel foam and soluble hemostatic gauze (Woundclot™, Core Scientific Creations, Israel). Bleeding from a bone resection site can be effectively controlled by applying bone wax.

Durotomy is not common but can occur mostly during working with the Kerrison rongeur blindly. There were three cases of durotomy made in the current case series of ULIF group. However, sizes of all three durotomies were not big enough to suture directly, and dural tear and cerebrospinal fluid leakage were controlled by attaching a fibrin collagen patch (TachoComb) and by maintaining lumbar drain for 5 to 7 days. However, if the size of durotomy is big, the nerve root is extruded and the TachoComb is not stabilized on the torn dural membrane, and we recommend direct dural repair. Techniques of dural suture to apply for dural tear following minimally invasive spinal surgeries could be applicable as well in the procedures of UBE decompression and ULIF [2].

In numerous studies, fusion rates of minimally invasive and open lumbar interbody fusion were not significantly different, and the mean fusion rate of each procedure was greater than 90% [10, 13]. The current two groups demonstrated fusion with definite and probable grades in more than 90% of patients, and the fusion rates were not significantly different between the two groups. However, less patients were graded as definite fusion in the ULIF group (71%) than in the PLIF group (83%) with a statistical trend, and significantly less cases of definite fusion and more cases of probable fusion were in the ULIF group than in the PLIF group.

No significant difference in fusion rate between the ULIF group and the PLIF group illustrates that ULIF is as effective as PLIF in bony fusion. However, fewer cases with definite fusion and more with probable fusion in the ULIF group than in the PLIF group also indicate that current ULIF is still midway in the learning curve with regard to improving the fusion grade.

However, radiological outcomes determined by the plain radiograph should be less accurate in assessing spinal fusion and instrumentation failure when compared with those by the CT scan. This is a limitation of this retrospectively study. To make up an inaccuracy of a plain radiograph, two-step grading using two observers' assessments was utilized to determine final radiological outcomes in this study (Fig. 5).

Techniques of endoscopic procedures require significant time with respect to improving the learning curve [7]. Gibson et al. [4] reported that all five revisions came from cases where transforaminal endoscopic discectomy occurred within two thirds of their case series of 70 patients. Therefore, ULIF is recommended after the surgeon reaches a plateau in performing UBE decompression, and the surgeon should focus more on achieving secure fusion when he/she attempts ULIF.

Based on the current case series and more experience with our later cases, the indication of ULIF could be suggested as any cases of lumbar spinal stenosis and spondylolisthesis with Meyerding grades I and II (patients with grade II were not in the current ULIF group). However, ULIF is limited (should be excluded) in fusion of severe forms of spondylolisthesis such as Meyerding grade III and IV spondylolisthesis, spondyloptosis, and spondylolisthesis with fused segment that require subtotal to total resection of bilateral facet joints.

Conclusions

No cases of transfusion done and less pain in immediate postoperative times indicate that ULIF is a less invasive procedure than conventional PLIF. Improvement in back pain, leg pain, and ODI at the last follow-up, low complication rate, and a fusion rate ≥ 90% in the ULIF group were not statistically different with the PLIF group, which indicates that ULIF is as effective as PLIF in improving clinical outcomes and obtaining fusion.

However, a longer operation time, no cases of spondylolisthesis more severe than grade II, and a blind space during cage insertion are probably limitations of current ULIF. Fewer cases with definite fusion and more with probable fusion in the ULIF group than in the PLIF group indicate that current ULIF is still midway in the learning curve with regard to improving the fusion grade.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Ethical approval was obtained from the Institutional Ethics Committee of the Ministry of Health and Welfare in South Korea (P01-201810-21-006).

Informed consent Informed consent was obtained from all individual participants included in the study.

References

1. Basques B, Golinvaux N, Bohl D, Yacob A, Toy J, Varthi A, Grauer J (2014) Use of an operating microscope during spine surgery is associated with minor increases in operating room times and no increased risk of infection. Spine 39:1910–1916
2. Boukebir M, Berlin C, Navarro Ramirez R, Heiland T, Schöller K, Rawanduzy C, Kirnaz S, Jada A, Härtl R (2017) Ten-step minimally invasive spine lumbar decompression and dural repair through tubular retractors. Open Neurosci J 13:232–245
3. Elkan P, Sten Linder M, Hedlund R, Willers U, Ponzer S, Gerdhem P (2016) Markers of inflammation and fibrinolysis in relation to outcome after surgery for lumbar disc herniation. A prospective study on 177 patients. Eur Spine J 25:186–191
4. Gibson JNA, Subramanian A, Scott CEH (2017) A randomised controlled trial of transforaminal endoscopic discectomy vs microdiscectomy. Eur Spine J 26:847–856
5. Hara M, Takahashi H, Yokoyama Y, Wada A, Hasegawa K, Iida Y (2015) Comparison of the invasiveness of conventional discectomy and microendoscopic discectomy for lumbar disc herniation: differences in the methods of approach. Asian J Endosc Surg 8:40–47
6. Heo D, Son S, Eum J, Park C (2017) Fully endoscopic lumbar interbody fusion using a percutaneous unilateral biportal endoscopic technique: technical note and preliminary clinical results. Neurosurg Focus 43:E8–E8
7. Hsu H-T, Chang S-J, Yang S, Chai C (2013) Learning curve of full-endoscopic lumbar discectomy. Eur Spine J 22:727–733
8. Hwa Eum J, Hwa Heo D, Son S, Park C (2016) Percutaneous biportal endoscopic decompression for lumbar spinal stenosis: a technical note and preliminary clinical results. J Neurosurg Spine 24:602–607
9. Jacquot F, Gastambide D (2013) Percutaneous endoscopic transforaminal lumbar interbody fusion: is it worth it? Int Orthop 37:1507–1510
10. Jin Tao Q, Yu T, Mei W, Xu Dong T, Tian Jian Z, Guo Hua S, Lei C, Yue H, Zi Tian W, Yue Z (2015) Comparison of MIS vs. open PLIF/TLIF with regard to clinical improvement, fusion rate, and incidence of major complication: a meta-analysis. Eur Spine J 24:1058–1065
11. Komp M, Hahn P, Oezdemir S, Giannakopoulos A, Heikenfeld R, Kasch R, Merk H, Godolias G, Ruetten S (2015) Bilateral spinal decompression of lumbar central stenosis with the full-endoscopic interlaminar versus microsurgical laminotomy technique: a prospective, randomized, controlled study. Pain Physician 18:61–70
12. Lee C, Choi M, Ryu D, Choi I, Kim C, Kim H, Sohn M (2018) Efficacy and safety of full-endoscopic decompression via interlaminar approach for central or lateral recess spinal stenosis of the lumbar spine: a meta-analysis. Spine (Phila Pa 1976) 43:1756–1764. https://doi.org/10.1097/BRS.0000000000002708
13. Lee K, Yue W, Yeo W, Soehamo H, Tan S (2012) Clinical and radiological outcomes of open versus minimally invasive transforaminal lumbar interbody fusion. Eur Spine J 21:2265–2270
14. Lee S, Lee J, Yeom J, Kim K-J, Kim H-J, Chung S, Kang H (2010) A practical MRI grading system for lumbar foraminal stenosis. AJR Am J Roentgenol 194:1095–1098
15. Rasouli MR, Rahimi-Movaghar V, Shokraneh F, Moradi-Lakeh M, Chou R (2014) Minimally invasive discectomy versus microdiscectomy/open discectomy for symptomatic lumbar disc herniation. Cochrane Database Syst Rev 4. John Wiley &Sons, Ltd, New York. https://doi.org/10.1002/14651858.CD010328.pub2
16. Ruan W, Feng F, Liu Z, Xie J, Cai L, Ping A (2016) Comparison of percutaneous endoscopic lumbar discectomy versus open lumbar

microdiscectomy for lumbar disc herniation: a metaanalysis. Int J Surg 31:86–92
17. Torudom Y, Dilokhuttakarn T (2016) Two portal percutaneous endoscopic decompression for lumbar spinal stenosis: preliminary study. Asian Spine J 10:335–342
18. Wang M, Grossman J (2016) Endoscopic minimally invasive transforaminal interbody fusion without general anesthesia: initial clinical experience with 1-year follow-up. Neurosurg Focus 40:E13–E13
19. Youn MS, Shin JK, Goh TS, Lee JS (2018) Full endoscopic lumbar interbody fusion (FELIF): technical note. Eur Spine J 27:1949–1955. https://doi.org/10.1007/s00586-018-5521-4