Neurospine 2020;17(4):910-920.
https://doi.org/10.14245/ns.2040302.151

Neurospine
pISSN 2586-6583 eISSN 2586-6591

Original Article

Corresponding Author
Shu Nakamura
https://orcid.org/0000-0002-8015-7571

Department of Orthopedic Surgery, Aichi Spine Hospital, 31-1Kamiike, Goroumaru, Inuyama-shi, Aichi 484-0066, Japan
E-mail: nakamura@itoortho.or.jp

Received: June 2, 2020
Revised: June 23, 2020
Accepted: July 2, 2020

Methods and Early Clinical Results of Percutaneous Lumbar Interbody Fusion

Shu Nakamura, Fjio Ito, Zenya Ito, Motohide Shibayama

Department of Orthopedic Surgery, Aichi Spine Hospital, Inuyama-shi, Japan

Objective: Percutaneous lumbar interbody fusion (PELIF) is a procedure that includes the use of new devices, which allow minimally invasive diskectomy under the percutaneous full-endoscopic guidance and safe percutaneous insertion of a standard-sized cage. This procedure can be applied to severe disk degeneration, spondylolisthesis, and all lumbar intervertebral levels including the L5–S1 level. We report the methods and the clinical outcomes of this procedure.
Methods: Percutaneous diskectomy was performed with an outer sheath cutter and other devices. A cage was inserted with an L-shaped retract-slider. Hybrid facet screw fixation was performed for severe disk degeneration without spondylolisthesis. Conventional percutaneous pedicle screw fixation was performed for spondylolisthesis. The subjects consisted of 21 patients, who underwent PELIF and were followed up for 1 year or longer.
Results: No complications related to cage insertion were detected. The mean visual analogue scale scores were improved from 6.1 to 1.9 for lower back pain in severe disc degeneration cases without spondylolisthesis, and from 7.6 to 1.0 for lower extremity symptoms in spondylolisthesis cases.
Conclusion: The clinical outcomes were favorable. PELIF was found to be a minimally invasive method that did not compromise safety and efficiency. PELIF is a possible therapeutic option that should be considered for not only spondylolisthesis at various intervertebral levels but also for severe disk degeneration because of its minimal invasiveness.

Keywords: Endoscopes, Lumbar vertebrae, Spinal fusion

INTRODUCTION

While aging progresses, with the advances in healthcare, treatment of age-related disorders is increasingly becoming important. Such disorders associated with severe disk degeneration affect numerous individuals. Moreover, regenerative medicine applications for the treatment of intervertebral disk-related issues are facing marked challenges. Surgery is more effective than conservative therapy for accurately diagnosed low back pain due to disk degeneration.[1] Even in minimally invasive transforaminal lumbar interbody fusion (TLIF), Joseph et al.[2] reported the total complication rate was 19.2%. Lateral lumbar interbody fusion (LIF), in which the spinal canal is not manipulated, has been widely adopted in recent years, but complications specific to this approach have also been reported.[3-7] Joseph et al.[2] reported the total complication rate was 31.4%, that is not negligible. Percutaneous posterolateral LIF (PPL-LIF), which is termed in this study inclusively about LIF performed percutaneously by the posterolateral approach through Kambin's triangle, can be regarded as the least invasive procedure. However, it is performed in only a few institutions because of some problems.

We have previously reported percutaneous LIF (PELIF), which is one of PPL-LIF and characterized by minimally invasive diskectomy under percutaneous full-endoscopic guidance and safe insertion of a standard-sized cage larger than a sheath using new devices.[8] Because this is not a pre-existing procedure, we have been cautious about applying it to only a small number of patients. Despite the small number of patients treated with this procedure, it appears to be useful. We report our experience and outcomes with PELIF.

MATERIALS AND METHODS

Following approval by the Institutional Review Board (IRB) of Aichi Spine Hospital (IRB No. IR18302), this procedure was indicated for patients who met the following criteria:

(1) Patients with severe disk degeneration, i.e., those with chronic low back pain who did not respond to conservative therapy and showed magnetic resonance imaging (MRI) findings of Modic change type 1: high intensity in the vertebral bodies on T2 fat-suppressed images above and below the thinned intervertebral disks, and computed tomography (CT) findings of a marked decrease in the intervertebral disk height and/or of the intradiscal vacuum phenomenon where spontaneous interbody union is unlikely to occur. When a definitive diagnosis is required, temporary pain relief can be accomplished with a selective disk block.

(2) Patients with degenerative spondylolisthesis or spondylolytic spondylolisthesis with intervertebral instability complicated by spinal canal stenosis and/or intervertebral foramen stenosis. Intervertebral instability was defined as Meyerding grade II or higher or a combination of a range of motion of the intervertebral angle of 10° or greater and posterior dilation angle of 5° or greater during flexion.

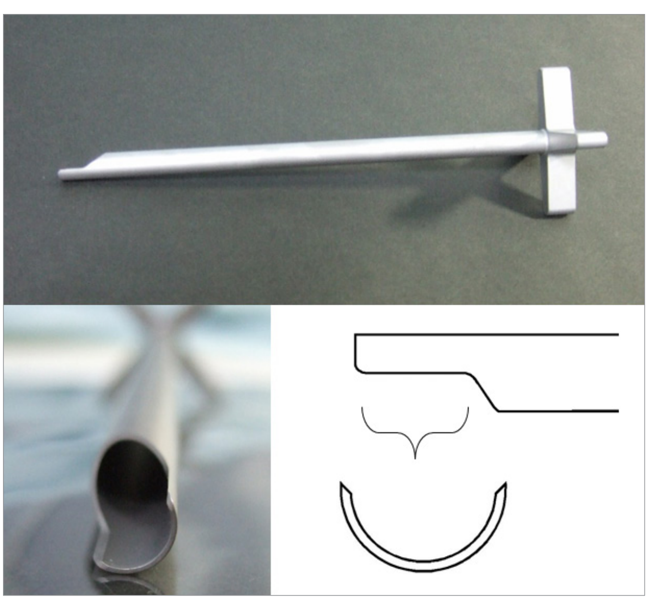

Fig. 1. Appearance of the outer sheath cutter. Although the outer diameter of the outer sheath cutter is the same as that of the standard outer sheath of full-endoscope, it has a beak with bilateral side edges and a cross handle.

Pyogenic diskitis, osteoporosis, and abnormal nerve root bifurcation were excluded from the indications.

1. Surgical Procedure

Under general anesthesia, the patient was placed in the prone position on a radiolucent operating table, and a fluoroscopic apparatus was set in place. Neurologic monitoring was performed by free-run electromyography.

A spinal needle was inserted to puncture the affected intervertebral disk from its posterolateral side to the proximity of its center via the transforaminal approach. Before proceeding to the next step, a second spinal needle was inserted on the other side, as it is easy to confirm the position of the 2 needles under fluoroscopic guidance at this step. Typically, foraminotomy is unnecessary. A dilator, an outer sheath cutter, and a standard full-endoscope were inserted in sequence on one side. The outer sheath cutter was a contrived device with the same outer diameter (7.5 or 8 mm) as that of standard sheaths used in percutaneous full-endoscopic lumbar diskectomy (PELD) for disk herniation, having a semicircular beak with bilateral side edges of single edge shape, and a cross handle at the proximal end (Figs. 1-3). The intervertebral disk was detached from the bony endplates with the side edges at the beak of the sheath, by rotating and swinging, and then extirpated with forceps under full-endoscopic view. Although this can be done with a standard duck-billed sheath, the intervertebral disk can be resected more efficiently with the outer sheath cutter. The detailed procedure was as follows: the outer sheath cutter was inserted to the inter-

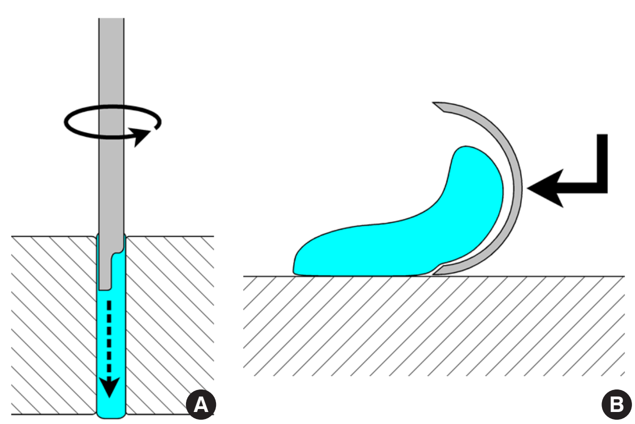

Fig. 2. (A, B) How to use the outer sheath cutter. The outer sheath cutter is rotated or swung to detach the intervertebral disk from the vertebral bodies with its side edges.

vertebral space over the dilator, positioning the beak caudomedially. The sheath was rotated and advanced from the dorsal to the ventral side of the intervertebral disk mainly under fluoroscopic guidance. Using this maneuver, a large volume of the intervertebral disk was extirpated at once (Fig. 2A). After this maneuver was repeated in some directions, the residual intervertebral disk was further resected by swinging the sheath under full-endoscopic view (Fig. 2B). A specially manufactured expandable cutter (Fig. 4) that could be inserted into working

Fig. 3. Intraoperative use of the outer sheath cutter. Under the full-endoscopic or fluoroscopic guidance, the intervertebral disk is detached. A cross handle facilitates rotation of the outer sheath cutter.

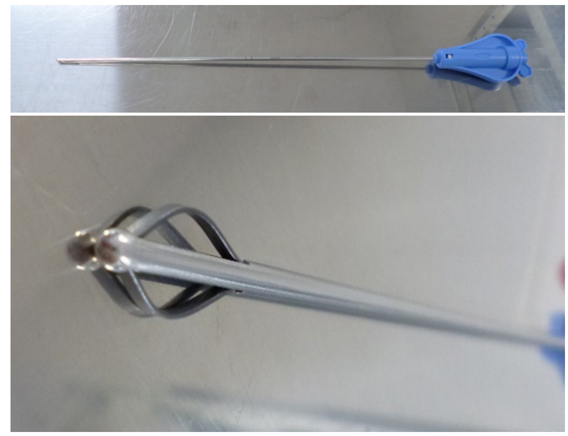

Fig. 4. Expandable blade cutter. The expandable blade cutter is inserted into full-endoscope and used for the areas outside the accessible range of the outer sheath cutter and depressed parts. When the knob at the proximal end is turned, the blade at the tip is expanded (lower panel). The tip of the blade is not fixed. If a mass of cartilage caught by the blade is too large, the mass can be removed by retracting the blade.

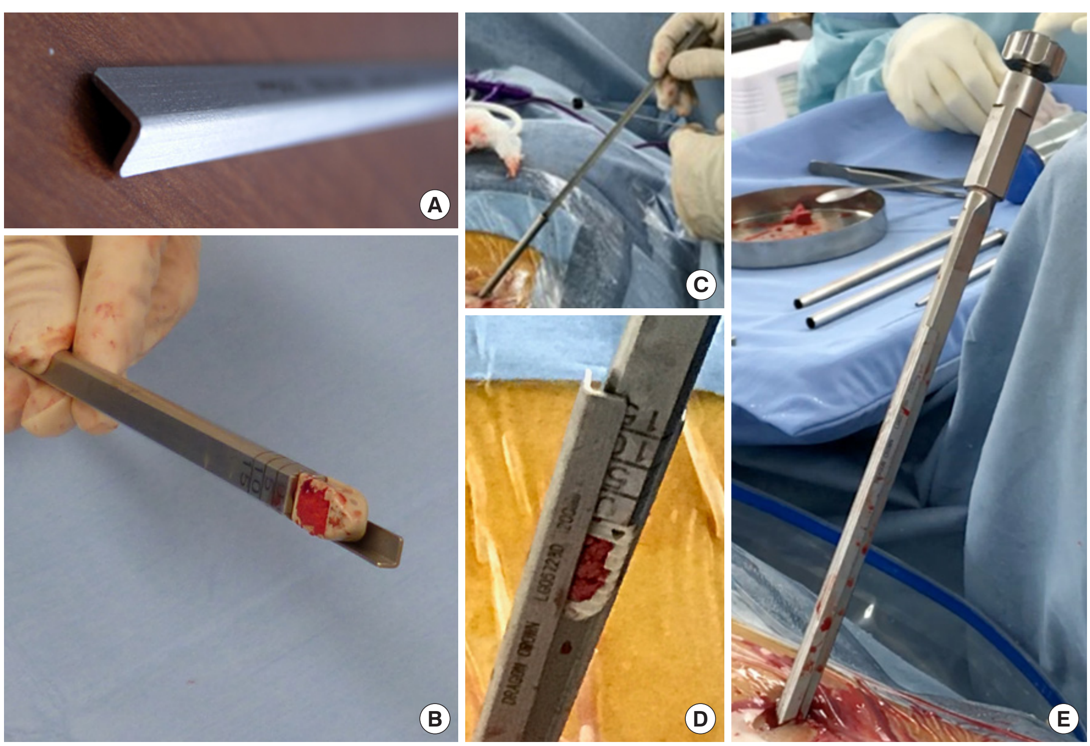

Fig. 5. L-shaped retract-slider. The corner of the L-shape is rounded (A), and the 2 inside surfaces are fit to the cage (B). After the L-shaped retract-slider is inserted into the sheath (C), the sheath is removed. When 2 L-shaped retract-sliders are used, they are arranged to enclose the cage (D, E).

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channel of full-endoscope was used for the depressed parts and areas outside the accessible range of the outer sheath cutter. When the knob at the proximal end was turned, the blade at the tip expanded and enabled the detachment of cartilage in areas beyond the long axis of the cutter. A ready-made bendable drill could be used for the same purpose. After the diskectomy was almost completed on one side, the outer sheath cutter was exchanged for a cylindrical outer sheath. Then, the operator moved to the opposite side. The intervertebral disk was also resected from the opposite side in the same manner. When it was sufficiently resected, the cavity was connected at the center.

After diskectomy was completed, an L-shaped retract-slider

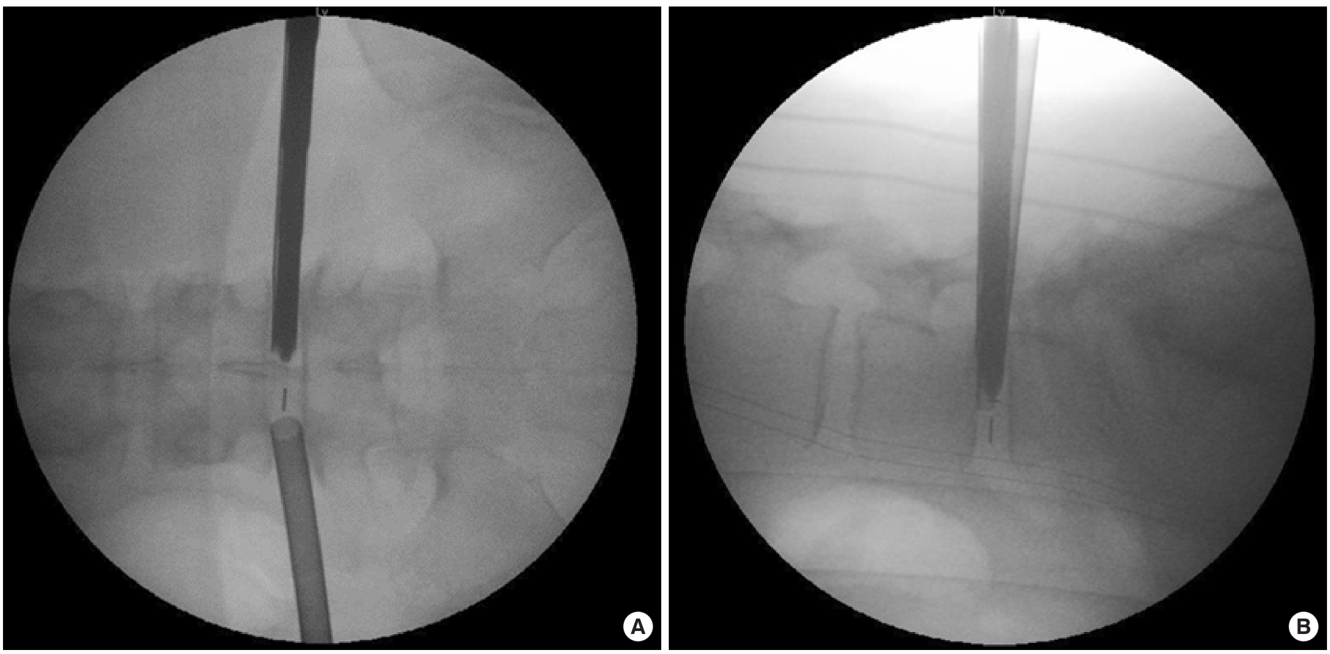

Fig. 6. Fluoroscopic image during cage insertion. While the sheath on the opposite side is not removed to keep the intervertebral space widened, a cage is inserted along the L-shaped retract-slider under fluoroscopic guidance.

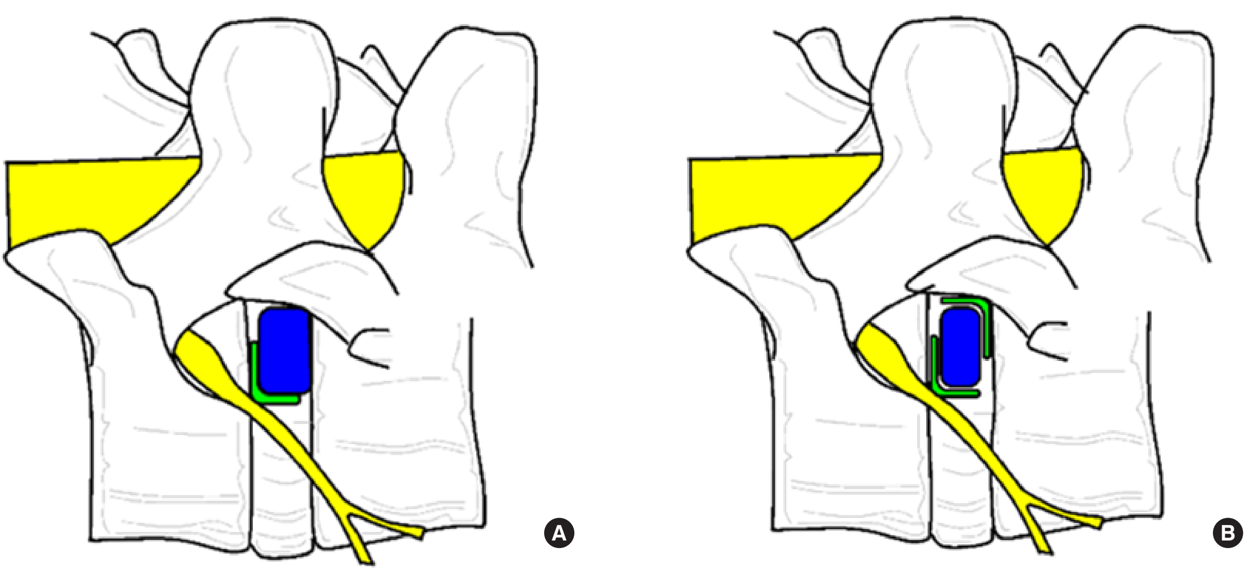

Fig. 7. Illustration of cage insertion. The exiting nerve root is reliably protected by placing the 2 exterior surfaces of the retract-slider on the lateral cranial side. (A) Usually, 1 retract-slider is sufficient for cage insertion, as shown in the left illustration. (B) When a large cage is inserted, 2 retractors are used, as shown in the right illustration.

(Fig. 5) was used for cage insertion. Its cross section was L-shaped with 2 straight lines and a rounded corner, and its length was longer than that of the outer sheath. The retract-slider was inserted into one of the sheaths. While the retractor was pushed with a dilator to retain the tip of the retractor in the intervertebral space, the sheath was removed. The outer sheath of other side was not removed at this time (Fig. 6). The 2 exterior surfaces of the retract-slider were placed on the lateral cranial side to protect the exiting nerve root (Fig. 7). A bullet-box-shaped cage, which is commonly used for TLIF and other procedures, was used. Under fluoroscopic guidance, this cage attached to a cage inserter was inserted along the inside of the retract-slider (Figs. 5, 6). In case of inserting a large cage, 2 retract-sliders were inserted and arranged to enclose the cage (Figs. 5D, 7B). Bone grafts were harvested from the ilium with a cylindrical sheath and trephine beforehand; after setting up the fluoroscope to match the inclination of the posterior ilium, the trephine was inserted into an outer sheath and hammered between the inner and outer plates of the ilium to collect the cancellous bone. The harvested bone was mixed with β-tricalcium phosphate artificial bone with a continuous air-hole porous structure, into which bone-marrow blood permeated under negative pressure. The bone grafts were implanted through the cylindrical sheath on the opposite side before and after the cage insertion.

In cases with severe disk degeneration without spondylolisthesis, we performed hybrid facet screw (HFS) fixation for affected levels other than the L5–S1 (Figs. 8C, 9, 10), and bilateral transfacet pedicle screw (TFPS) fixation for the L5–S1 level (Fig. 8A). Percutaneous pedicle screw (PPS) fixation was performed for spondylolisthesis, spondylolytic spondylolisthesis, and cases of combined decompression surgery (Figs. 11, 12). When facet screw fixation was performed, a 13-G bone biopsy needle was inserted under radiographic guidance, and a fully threaded cannulated screw was inserted by passing through the guidewire. For translaminar facet screw fixation, a bone biopsy needle was inserted under fluoroscopic guidance in the vertebral arch axial projection. In PPS fixation, the lower PPS was inserted from the same skin incision made for diskectomy and cage insertion.

Although neither foraminotomy nor laminotomy is usually performed, we performed foraminotomy and PPS fixation for marked intervertebral foramen stenosis. For spinal canal stenosis due to prominent bony elements, we performed percutaneous full-endoscopic laminotomy (PEL) and PPS fixation.

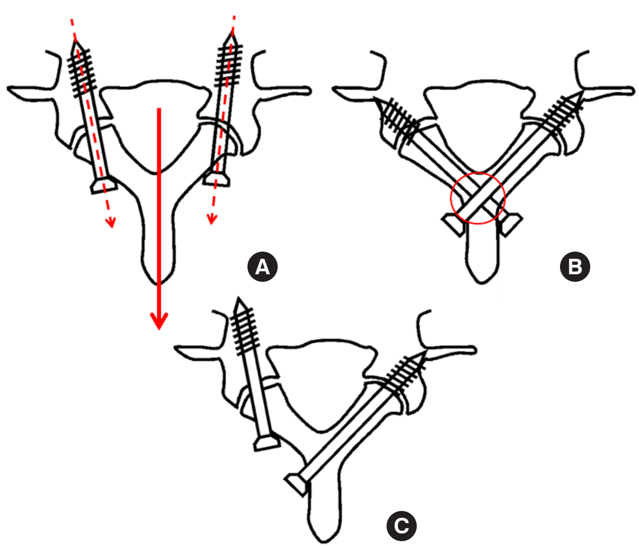

Fig. 8. Facet screw fixation. (A) Transfacet pedicle screw fixation. Transfacet pedicle screws are used at the L5–S1 level. At cranially higher intervertebral levels, the right and left screws are aligned nearly parallel, as shown by the dotted lines with arrowheads. The mechanical weakness in the direction indicated by the red arrow is a concern. (B) Translaminar facet screw fixation. Because 2 screws intersect each other in a narrow area (red circle), it is difficult to prevent them from interfering with the optimal position. (C) Hybrid facet screw fixation. This technique is a combination of the 2 techniques described above and resolves the demerits of each technique. It is applied at the levels other than the L5–S1.

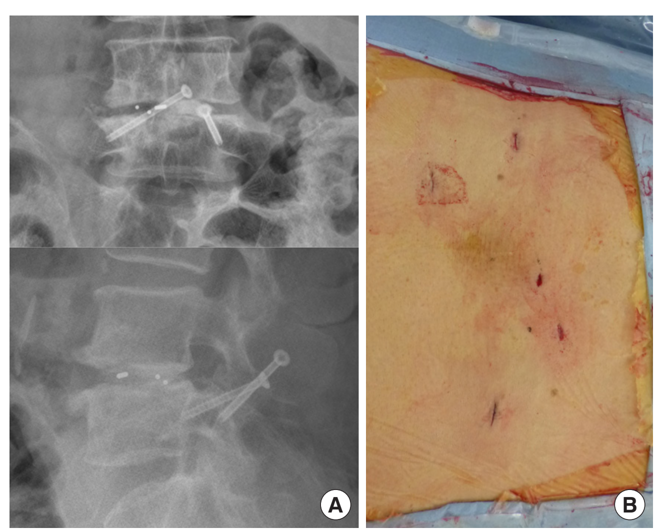

Fig. 9. Patient 1 undergoing percutaneous lumbar interbody fusion using hybrid facet screw fixation (PELIF-HFS). PELIF-HFS was performed using a polyetheretherketone cage (Vusion OS, Ortho Development, Draper, UT, USA) for a patient with chronic low back pain due to severe disk degeneration at the L4–5 level (A: postoperative radiograph). (B) The skin incisions are small.

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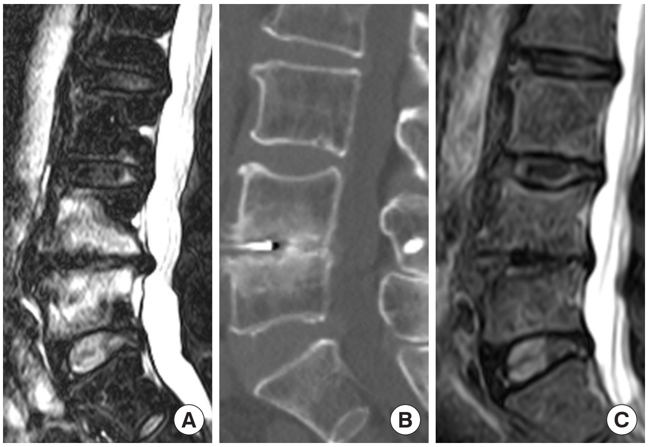

Fig. 10. The same patient is shown in Fig. 9. Marked Modic change type 1 was observed at the L4–5 level before surgery (A: preoperative magnetic resonance T2 fat-suppressed image). Percutaneous lumbar interbody fusion using hybrid facet screw fixation was performed. Subsequently, bone union was achieved (B: postoperative computed tomographic image at 3 years), and the Modic change disappeared (C: postoperative magnetic resonance T2 fat-suppressed image at 3 years).

The patients were allowed to walk 6 hours after surgery, and wore a corset for approximately 6 weeks.

2. Imaging Assessment

MRI, including T2 fat-suppressed sagittal imaging, CT, and dynamic radiography (with the frontal and lateral views in the standing position and the lateral views in the flexion and extension positions) were performed before surgery and during the postoperative follow-up. Bone union was also evaluated by CT and dynamic radiography.

3. Clinical Assessment

Lower extremity pain and low back pain were measured with a visual analogue scale (VAS, 10–0) before and after surgery (1, 3, 6, 12, 24 months). In addition, disability scored by Oswestry Disability Index (ODI).

4. Subjects

The subjects were 21 patients, who underwent PELIF in or after January 2016 and were followed up for 1 year or longer.

RESULTS

The mean age was 61.6 years (range, 45–79 years). There were 8 men and 13 women. The mean follow-up period was 20.3 months (range, 12–36 months). HFS fixation was performed in 10, TFPS fixation (at the L5–S1 level) in 5, and PPS fixation in 6 patients. Including duplicates, there were 17 patients with severe disk degeneration, 7 with spinal canal stenosis, 5 with intervertebral foramen stenosis, and 6 with spondylolisthesis (4 with grade II degenerative spondylolisthesis, 1 with grade II spondylolytic spondylolisthesis, and 1 with posterior spondylolisthesis). The affected intervertebral disks were located at the L2–3 level in 2 patients, L3–4 in 3, L4–5 in 11, and L5–S1 in 5. In this study, there was 1 patient who simultaneously underwent PEL, and no patients who simultaneously underwent foraminotomy.

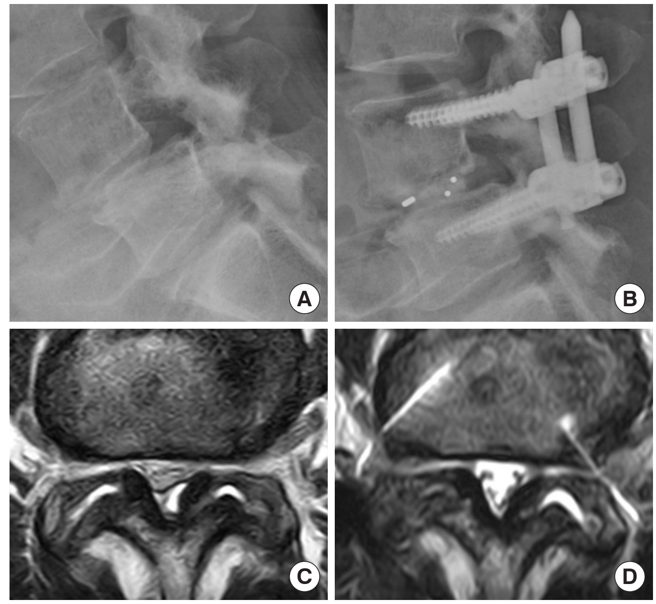

Fig. 11. Patient 2 undergoing percutaneous lumbar interbody fusion using percutaneous pedicle screw fixation (PELIF-PPS). PELIF-PPS using a polyetheretherketone cage (B: postoperative radiograph) was performed for spinal canal stenosis due to spondylolisthesis at the L4–5 level (A: preoperative radiograph, C: preoperative magnetic resonance T2-weighted image). Spinal canal stenosis was alleviated immediately after surgery (D: postoperative magnetic resonance T2-weighted image).

No complications related to cage insertion: hypesthesia, dysesthesia, or weakness due to exiting nerve root injury, were detected. Although the amount of blood loss was not measured, it was small. The mean operative time was 144 minutes (range, 113–183 minutes).

In 15 severe disc degeneration cases without spondylolisthesis, the mean VAS scores were improved from 6.1 ± 2.1 to 1.9 ± 1.4 for low back pain (mean improvement rate, 70.0% ± 18.3%), and from 3.9 ± 2.4 to 1.0 ± 0.7 for lower extremity symptoms (mean improvement rate, 70.5% ± 28.3%), before and after the

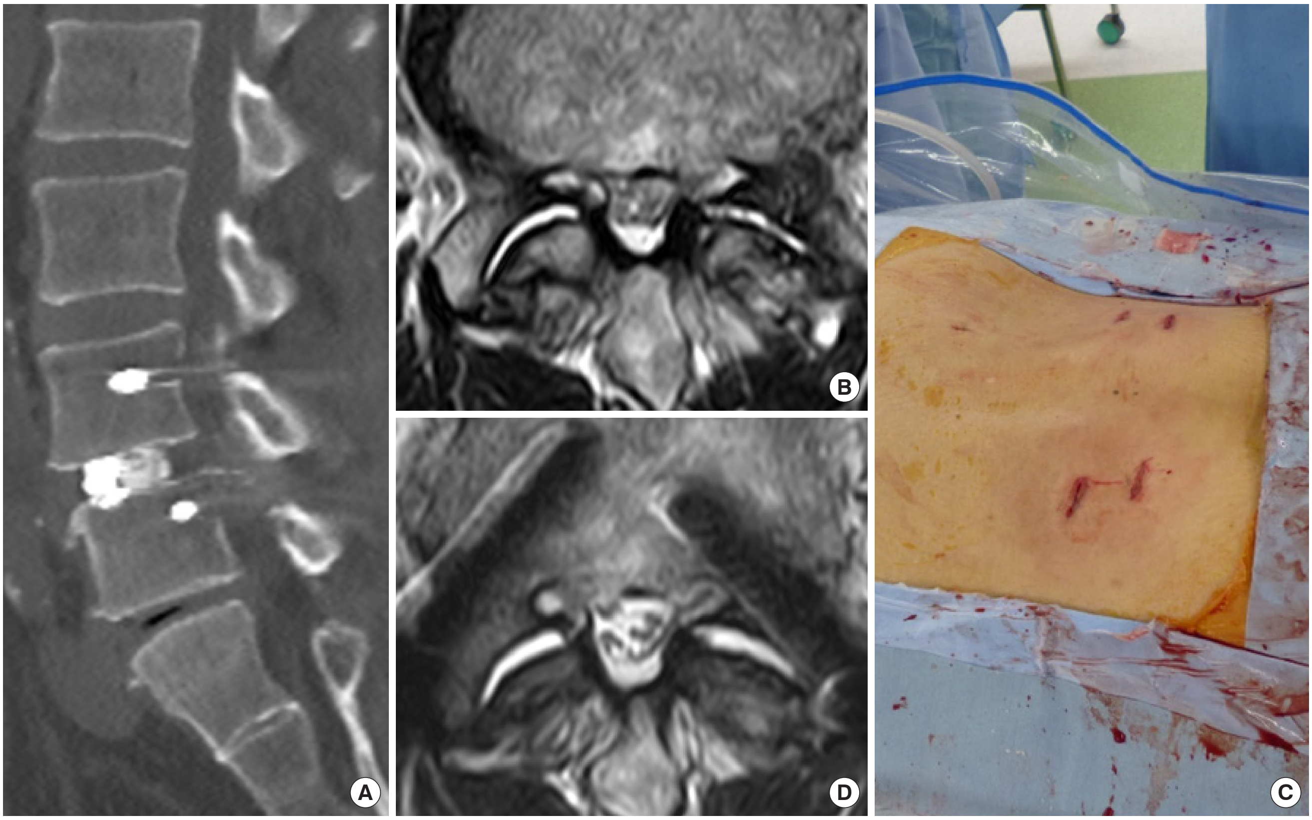

Fig. 12. Patient 3 undergoing percutaneous lumbar interbody fusion using percutaneous pedicle screw fixation (PELIF-PPS). PELIF-PPS using an expandable cage (RISE, Globus Medical, Audubon, PA, USA) (A: postoperative computed tomographic image) was performed for spinal canal stenosis due to spondylolisthesis at the L4–5 level (B: preoperative magnetic resonance image). (C) The cage and the caudal screw were inserted from the same skin incision. Spinal canal stenosis was alleviated immediately after surgery (D: postoperative magnetic resonance image).

surgery, respectively. The mean ODI scores were improved from 32.6 ± 6.9 to 7.4 ± 6.1.

In 6 spondylolisthesis cases, the mean VAS scores were improved from 4.6 ± 2.6 to 0.8 ± 0.4 for low back pain (mean improvement rate, 69.6% ± 35.7%), and from 7.6 ± 0.8 to 1.0 ± 0.6 for lower extremity symptoms (mean improvement rate, 86.1% ± 9.1%), before and after the surgery, respectively. The mean ODI scores were improved from 32.0 ± 4.3 to 8.3 ± 6.6.

There were no clinical and radiographic signs of nonunion in all patients, who underwent surgery using the standard techniques described above. In one patient, who underwent TFPS fixation without autogenous bone grafting to reduce skin incisions for esthetic reasons, delayed bone union was observed 1 year after the surgery. However, there were no loose screws, and the stability of the spine was confirmed by dynamic radiography. Low back pain, which was the chief preoperative complaint, was almost relieved, and patient satisfaction was also rated as excellent.

DISCUSSION

1. Classification and History of PPL-LIF

Although the above-mentioned PPL-LIF could be regarded as a least invasive LIF, it is in the trial and development stage and there are unique techniques for this procedure, which we classified according to the grafting and insertion methods into the intervertebral space (Table 1).[8-26]

Among the insertion techniques utilizing the usual sheath (usual sheath [US] group), the insertion technique of comminuted bone and/or other materials without using any cages (without cage subgroup) is the oldest technique, but it has been reported even recently.[9-13] Because of the lack of supporting structure in the intervertebral disk area, which is the main loading part of the lumbar spine, this technique appears to be principally inferior in terms of stability. In addition to the technique described above, the US group included a technique using a special spacer; B-Twin spacers (special spacer subgroup).[14,15]

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Table 1. Classification and history of percutaneous lumbar interbody fusion by the posterolateral approach

Usual sheath insertion (US) group
Without cage subgroup
Leu and Hauser[9] 1996: OD 7.5 mm
Osman[11] 2012: OD?
Wang and Grossman[12] 2016: OD 8 mm, OptiMesh
Krishnan et al.[13] 2018: OD 8 mm
Special spacer subgroup
Folman et al.[14] 2003: OD?, B-Twin spacer
Lee et al.[15] 2017: OD 7 mm, B-Twin spacer
Large sheath insertion (LS) group
Morgenstern[16] 2010: OD 12.9 mm
Morgenstern and Morgenstern[17] 2015: OD 12 mm, PerX360 system, expandable cage
Syed and Voyadzis[18] 2016: OD 12 mm, PerX360 system, expandable cage
Wu et al.[19] 2018: OD 16–19 mm, PELIF/EndoLIF
Youn et al.[20] 2018: OD 16–20 mm
Fiori et al.[21] 2019: OD?, IntraLIF, expandable cage
Silva et al.[22] 2019: OD 16.5 mm?
Yang et al.[23] 2019: OD 13 mm?, expandable cage
Non-sheath insertion (NS) group
Katzell[24] 2014: OD 9 mm, OLLIF, through K-wire, Zeus-O cage
Abbasi and Abbasi[25] 2015: OD?, OLLIF, through K-wire, Zeus-O cage
Retract-slider insertion (RS) group
Nakamura and Taguchi[8] 2017: OD 7.5 mm
Nagahama et al.[26] 2019: OD 8 & 10.5 mm

OD?, the outer diameter of the sheath is not provided. When only the inner diameter is provided, the outer diameter is expressed as the sum of the inner diameter and 1.5 mm accompanied by "?".

The B-Twin spacer is a nonbox, cylindrical spacer with expandable spikes that do not support the bony endplate on the surface. The technique using this spacer was reported to be associated with a high incidence of nonunion and device breakage.[15]

Next, the cage insertion technique, with a large-diameter sheath (LS group), has been described in many reports in recent years.[16-23] The smallest cage used for TLIF is 8 mm in width and 7 mm in height. The outer diameter of a sheath that can contain this cage computationally needs to be 12 mm or more. Based on measurement in cadavers, a sheath with an outer diameter of 8.8 mm or greater deviates from Kambin's triangle at the L4–5 level, and a sheath with an outer diameter of 7.9 mm or greater deviates at the L3–4 level.[27] Even after foraminotomy, the longitudinal safety margin does not increase. When large-diameter sheaths are used, they may injure the exiting nerve root during their insertion and compress it for an extended period of time depending on their angle during manipulation of the intervertebral disk. Jacquot and Gastambide[28] reported that perioperative radicular trauma rate was 14% in percutaneous endoscopic transforaminal LIF.

Furthermore, there are also reports of an insertion technique of a special cage with a long pointed tip resembling an arrowhead without sheath (non-sheath group).[24,25] In this technique, although the intervertebral disk is treated through a sheath, the cage is inserted over the guidewire after the sheath is removed. However, because the exiting nerve root cannot be reliably protected, there have been cases of nerve injury reported.[24]

Although we used standard sheaths in our procedure, they were removed, unlike any of the techniques described above, and retract-sliders that had been inserted beforehand were used for cage insertion (retract-slider group).[8,26] Our previous report[8] was the first to describe this technique. By using a retract-slider, our procedure enables the insertion of a cage larger than a sheath, while protecting the exiting nerve root. Our procedure is minimal invasive due to percutaneous full-endoscopic operation, free from constraints due to the sheath size in the cage size, and safe.

2. Requirements for Retractors

For the exiting nerve root, while prolonged compression should be avoided, prevention of direct nerve injury and involving nerve damage due to the catching of the perineural membrane is the most crucial matter. For this reason, the retractors should meet the following 3 requirements: (1) The retractor should cover the lateral cranial side of the cage against the course of the exiting nerve root; (2) the retractor should fit, as wide as possible, to the 2 sides forming the corner of the cage to prevent the cage from being deviated in the cranial or lateral direction by an external force at the time of cage insertion; (3) the retractor can be inserted into a sheath. The L-shaped retract-slider with a rounded corner, which was used in our procedure, appears to be an optimal device to meet these requirements. In PELIF, when a cage is inserted, the retractor may be laterally displaced and push the root at the intervertebral disk level. However, this displacement occurs toward the open side and is only temporary. Thus, we do not consider that this poses any problems.

3. Fixation Techniques

PPS fixation, which is commonly performed as minimally invasive LIF, requires large skin incision that is not very suitable to the term "percutaneous." To develop a true percutaneous LIF, we adopted facet screw fixation and refined it into HFS fixation.[8] HFS fixation can be achieved due to the features of PELIF that do not require foraminotomy.

As shown in Fig. 8, HFS fixation is a combination of TFPS and translaminar facet screw fixation and resolves the demerits of each technique. However, bilateral TFPS fixation is more effective at the L5–S1 level because of the thin vertebral arch and the large angle between the right and left screws due to the wide facet joint interspace.

Multiple studies, including those on biomechanics, have reported that facet screw fixation achieves similar stability to that of pedicle screw fixation.[29,30] However, spondylolytic spondylolisthesis is, of course, not indicated for facet screw fixation. In patients with a deformed facet joint as seen in those with spondylolisthesis, as well as in patients with defects in the vertebral arch or facet joint due to decompression surgery, there is a concern that the stability may be affected by the fragility of the base into which screws are inserted. Thus, we performed conventional PPS fixation in such patients.

4. Merits and Demerits of Using Sheaths for PELD and Countermeasures Against the Demerits

The merits of using a standard-sized, non–large-diameter sheaths for PELD, are as follows: (1) The standard-sized sheath can be safely inserted through the narrow Kambin's triangle from the posterolateral side, and it can be also safely tilted during the operation. (2) The sheath can easily be moved between vertebrae. (3) Because residual intervertebral disk can be endoscopically confirmed, diskectomy can be performed with certainty. (4) With the advantage of the features facilitating the minimally invasive bilateral approach, bilateral bed preparation can increase the recipient bone graft area, and a sufficiently wide area of the intervertebral disk can be resected without forcibly tilting the sheath. (5) Foraminotomy is unnecessary. (6) Repeated insertion and removal of sharp instruments for diskectomy near the nerve is unnecessary.

As for the demerits, it was considered that efficient diskectomy would be impossible as only small devices could be inserted into a small sheath. However, the efficiency has been substantially improved by the new device: outer sheath cutter, simultaneously using sheaths as cutters. In addition, the inexpensive, expandable blade cutter, which is developed by simply modifying a device used for percutaneous vertebroplasty, can be used as a substitute for curved devices. The bendable drill, which is more expensive, is also useful. Furthermore, we have performed diskectomy using 5-mm forceps through the outer sheath without a scope, as well as an electric shaver and a curette. Ultimately, the outer sheath cutter is the most useful device. PELIF can be performed within 2 hours by surgeons who skilled in the technique.

5. The Height of the Cages

Because the effect of LIF is reportedly attributed to stabilization,[31,32] marked widening of the intervertebral space may not be necessary. When the intervertebral space needs to be widened further, the distractor is inserted using the L-shaped retract-slider on the other side and widens the intervertebral space, and a high cage is then inserted by enclosing it between the 2 retract-sliders, as described above (Fig. 7B). In addition, the use of the expandable cage facilitated the widening of the intervertebral space (Fig. 12).

6. Option of the Approach

In this study series, we inserted the cage before placing the screws in all patients. Intervertebral discectomy was performed from both sides to widen the graft area, and the intervertebral space was maintained by leaving the outer sheath on other side to insert the cage. However, after this study, we have sometimes performed the procedure unilaterally. In that case, PPS is placed on the other side to maintain the intervertebral space before inserting the cage.

CONCLUSION

Clinical outcomes of PELIF are favorable. PELIF was found to be a minimally invasive method that did not compromise safety and efficiency. PELIF is a therapeutic option that should be considered for not only spondylolisthesis at various intervertebral levels but also for severe disk degeneration because of its minimal invasiveness.

CONFLICT OF INTEREST

The authors have nothing to disclose.

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 https://doi.org/10.14245/ns.2040302.151