Retrospective Review

Percutaneous Transforaminal Endoscopic Lumbar Interbody Fusion for Degenerative Lumbar Diseases: A Consecutive Case Series with Mean 2-Year Follow-Up

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Background: Conventional open surgical procedures may cause massive dissections of the spine, higher perioperative complications, prolonged hospitalization, protracted rehabilitation programs and recovery. Percutaneous endoscopic lumbar interbody fusion (PELIF) is an evolving treatment option.

Objectives: To present the detailed procedure and preliminary clinical and radiologic results of PELIF for degenerative lumbar diseases.

Study Design: A retrospective cohort study.

Setting: A university affiliated tertiary hospital.

Methods: The medical records of patients with degenerative lumbar diseases who underwent PELIF between January 2016 and December 2017 were retrospectively reviewed. Surgical level, surgical time, blood loss, hospital length of stay, and perioperative complications were discussed. Patients were also evaluated for pain by the Visual Analog Scale (VAS), and functional assessment by the Oswestry Disability Index (ODI) and the 36-Item Short Form Health Survey (SF-36), including Physical Component Summary (PCS) and Mental Component Summary (MCS) preoperatively, postoperatively, and during the follow-up period.

Results: Thirty-nine consecutive patients (25 men and 14 women) with a mean age of 59.0 years (range, 39-77 years) were enrolled. The average surgical time was 213.8 ± 31.7 minutes (range, 185-324 minutes). Mean estimated blood loss was 25.0 ± 12.6 mL (range, 15-50 mL). At the latest follow-up visit, the VAS scores for back pain, leg pain, ODI, and SF-36 (MCS/PCS) scores improved 89.5%, 95.0%, 71.2%, and 37.5%/58%, respectively. Reoperations were performed in one patient for residual disc mass and one for misplacement of pedicle screw. Fusion was achieved in all patients.

Limitations: The presented results are preliminary and should be interpreted taking the limitations into account, including nonrandomized design, relatively small sample size, and less intensive follow-up period.

Conclusions: The presented PELIF technique seems to be a promising surgical alternative for the treatment of patients with specific degenerative lumbar diseases. Randomized studies with larger sample size and long-term follow-up duration are needed to validate the superiorities of this versatile surgery.

Key words: Endoscopic, minimally invasive spine surgery, lumbar interbody fusion, disc herniation, spondylolisthesis

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Open spinal fusions have been shown as a preferred surgical option to reduce pain, recover function, and increase quality of life in the treatment of a variety of lumbar spinal disorders (1). Although addressing the pathology adequately, open surgical procedures may cause massive dissections of the spine, higher perioperative complications, prolonged hospitalization, protracted rehabilitation programs and recovery (2). Given the increasing demand of shorter hospitalization, the desire for the geriatric patients to continue vigorous physical activities, and unsustainable increase of medical care costs, various less invasive procedures, including direct lateral lumbar interbody fusion (DLIF), anterior lumbar interbody fusion (ALIF), and oblique lumbar interbody fusion (OLIF) have gained popularity as practical alternatives to conventional open surgeries (3). Apparently, all these procedures with the use of tubular dilators in concert with specialized interbody cages and percutaneous screws fall under the umbrella name of "minimally invasive spine surgeries (MISS)," but each of them has distinct attributes and a unique set of potential complications. Therefore searching for newer surgical methods to achieve the goals of MISS, including minimized blood loss, neuromuscular destruction, pain intensity, shorter hospital stays, and accelerated recovery, is imperative.

Recently, with the advent of endoscopic techniques and medical apparatus, clinical applications of percutaneous endoscopic lumbar interbody fusion (PELIF) techniques have been attempted by several single-center case studies (2,4-7). PELIF is manipulated through typical Kambin's triangle with a similar surgical access as percutaneous endoscopic lumbar discectomy (PELD), and integrates endoscopic visualization, interbody implant, percutaneous fixation, and long-acting local anesthetics.

The purpose of the present study was to evaluate the clinical and radiologic results of PELIF for a variety of spinal diseases in a single institution with mean 2-year follow-up duration.

Methods

Patients

Consent was obtained from each patient, and the local institutional review board approved the study. We retrieved the medical records of 39 consecutive patients treated with PELIF between January 2016 and December 2017 at our institution. The surgical indications of PELIF included (1) predominant unilateral or bilateral radiating leg pain with or without chronic back pain; (2) positive nerve root tension sign (sciatic or femoral nerve); (3) corresponding magnetic resonance imaging (MRI) and computed tomography (CT) images showing degenerative changes, segmental instability, or spondylolisthesis (8); and (4) refractory to nonsteroidal antiinflammatory medications combined with bedrest for 2 months. Patients with clinical symptoms related to intraspinal pathology, bony fracture, and diseases that impair bone quality (e.g., osteoporosis, other metabolic diseases, neoplasm, infection, or systemic diseases) were excluded. Pathologies at L5/S1 segment were excluded considering that the iliac crest may obstruct the cage insertion.

The baseline radiologic characteristics, including disc degeneration, central canal stenosis, and foraminal stenosis were retrospectively evaluated. Specifically, disc degeneration was graded according to the Pfirrmann classification (9). Central canal stenosis was divided into 4 grades as described by Lee et al (10): grade 0, no central canal stenosis; grade 1, mild stenosis with clear separation of each cauda equine; grade 2, moderate stenosis with some cauda equina aggregation; and grade 3, severe stenosis with the entire cauda equina as a bundle. Foraminal stenosis was also divided into 4 grades as described by Lee et al (11): grade 0, absence of foraminal stenosis; grade 1, mild stenosis with perineural fat obliteration in either vertical or transverse plane; grade 2, moderate stenosis with perineural fat obliteration in vertical and transverse planes without morphologic nerve root changes; and grade 3, severe stenosis with nerve root compression or morphologic change (Table 1).

The patients were also evaluated for baseline demographic characteristics, surgical level, operation time blood loss, length of hospital stay, and perioperative complications. Clinical outcomes were assessed using the Visual Analog Scale (VAS) for back (VAS-B) and leg (VAS-L) pain, the Oswestry Disability Index (ODI), and the 36-Item Short Form Health Survey (SF-36) preoperatively, immediately postoperatively, and at each follow-up interval.

Routine plain x-rays (standing anteroposterior, lateral neutral, flexion, and extension views), CT, and MRI were obtained preoperatively, which were used to calculate the exact point of skin entry for the needle insertion. Lumbar spine standing x-rays and/or CT were collected at each follow-up interval. Segmental instability was regarded as a slip of > 3 mm

in the neutral position, > 3 mm translation, or > 10 degrees angulation on flexion and extension views (7). The criteria used to define bone union were defined as follows: no radiolucency between the graft and the vertebral body, the presence of bridging osseous trabeculae on CT images, and < 3 mm of motion between the tips of the posterior spinous processes of the fused segments on flexion and extension lateral radiographs of the lumbar spine.

Table 1. *Baseline radiographic characteristics of all patients.*

Characteristic	Value
Disc degeneration (Pfirrmann Classification)	
Grade I	0
Grade II	3
Grade III	12
Grade IV	19
Grade V	5
Central canal stenosis	
Grade 0	4
Grade 1	13
Grade 2	16
Grade 3	6
Foraminal stenosis	
Grade 0	3
Grade 1	7
Grade 2	20
Grade 3	9

Surgical Technique

Local anesthesia supplemented with neuroleptic analgesia (dexmedetomidine 1 μg/kg during 10 minutes for loading dose, and 0.2-0.4 μg/kg per hour for maintenance dose) is performed during the decompression procedure. The epidural anesthesia (EA) tube is prepared preoperatively, but only when the patient complains about unbearable pain during bone harvest, cage insertion, and percutaneous pedicle screw placement procedures will EA be performed according to the standard EA technique (12). In short, the insertion point is 2 segments above the surgical segment. A total of 1% lidocaine 3 mL is applied initially, and 0.25% ropivacaine is added to adjust the sensory level and achieve the aim of sensory-motor separation.

The patient is placed in the prone position on the operating table and draped aseptically. The skin entry point has already been calculated from preoperative axial CT or MRI images, which varies from 8 to 12 cm depending on the patient's waist size and target pathology. Lidocaine 1% is administered to the skin, intervertebral foramen, and facet joint. An 18-G spinal needle is inserted and navigated toward the intervertebral foramen under image intensifier, and then replaced by a 0.8-mm blunt-tipped guidewire. A blunt-tapered obturator (TESSYS Endoscopic System, Joimax GmbH, Karlsruhe, Germany) is inserted over the guidewire by gentle twisting motions under image intensifier control. Then a beveled working cannula (8.5 mm of outer diameter, 7.5 mm of inner diameter) is passed over the obturator. After the obturator is withdrawn, a working channel endoscope (7.3 mm of outer diameter, 3.5 mm of working channel) is then introduced and placed diagonally on the spinal canal.

After identifying the facet joint via endoscopic visualization, capsule and cortical bone of facet joint are removed by using endoscopic burr and a low-energy bipolar radiofrequency. Next, osteotomy on superior articular process is performed, which paves the way for sufficient decompression and insertion of interbody implant. The neurologic decompression is performed as a PELD procedure. After clearing the adipose tissue and coagulating the bleeding points with a low-energy bipolar radiofrequency, epidural structures, including dura, posterior longitudinal ligament, ipsilateral and contralateral nerve roots can be visualized clearly, which ensure sufficient decompression of the ventral side of dura. If the fragments are too large to get through the working cannula, we can grasp the main fragment and withdraw the endoscope along with the forceps, keeping the working channel in place. The working channel is rotated to expose the traversing nerve root and lateral recess area. Then the working channel is outwardly rotated to confirm solid decompression of the exiting nerve root.

After a 2.0-mm wire is inserted, the channel is withdrawn gently by twisting motions and replaced by the working sheath (11.1 mm of inner diameter, Aaxter Co., Ltd, Taiwan, China) used for endoscopic interbody fusion. A series of endoscopic reamers and curettes (220 mm of length) are introduced into the disc space under image intensifier (Fig. 1A, B). Adequate disc space and end plate preparation are manipulated under fluoroscopic guidance and inspected through endoscopic visualization. Autologous bone will be harvested from the contralateral posterior superior iliac spine and placed into the frontal and contralateral area of disc space through the working sheath (Fig. 2A,

B). Then the expandable cage (9 mm of height, 22 mm of length, bullet shaped) is fixed on the cage holding rod and placed into the disc space under fluoroscopic guidance (Fig. 3A-C). The cage could be expanded to 12 to 13 mm of height when fixed. Again, inspect the disc space and ventral side of the dura under endoscopic visualization before withdrawing the working sheath (Fig. 3D).

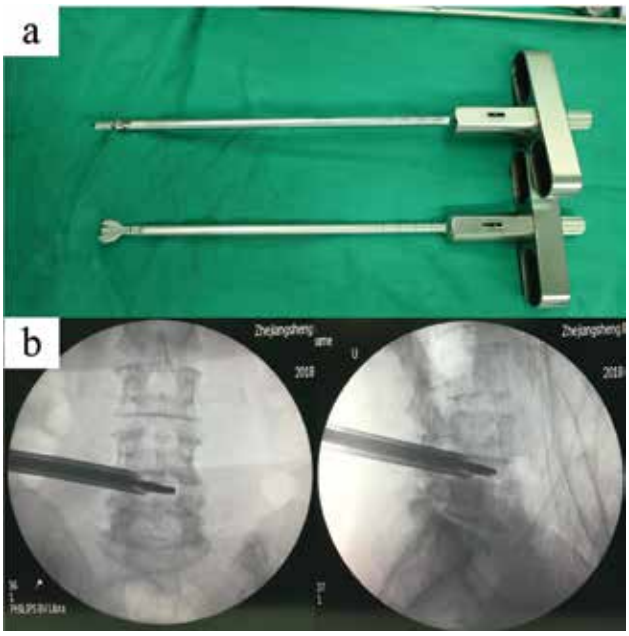

Fig. 1. *The endoscopic reamers with different diameters (5.6 mm or 6.5 mm in width and 220 mm in length) (A). The disc space and end plate preparation are prepared under image intensifier (B).*

Lidocaine 1% is administered to the skin and evenly along the tracts of percutaneous pedicle screw. The Jamshidi needles are inserted followed by the placement of K-wires through the hollow of needles under image intensifier (13). A series of obturator (7.5 mm, 13.2 mm, and 15 mm of outer diameter) are placed along with the K-wires. The awl and ball handle probe are introduced after withdrawing the outer working obturator. Then the pedicle screws (6.5 mm of diameter, 45 or 50 mm of length) are inserted, and 2 rods are attached to the screws subfascially (Fig. 4A, B). Remove all the instruments after final tightening of the screw extenders. Finally, close all 5 incisions (about 1 cm in length) layer by layer (Fig. 4C).

Postoperative CT and MRI are taken 2 days after surgery and evaluated in terms of extent of decompression.

Statistical Analysis

We calculated the following summary statistics, means and standard deviation for continuous variables, and frequencies and percentages for categorical variables. Statistical verification was determined using SPSS for Windows version 17.0.1 (SPSS Inc., Chicago, IL). The differences in preoperative, postoperative, and final follow-up VAS, ODI, and SF-36 scores were evalu-

Fig. 2. *Autologous bone chips (1.5-2 cm in length) are harvested from the contralateral posterior superior iliac spine (A, B) and placed into the frontal and contralateral area of disc space through the working sheath.*

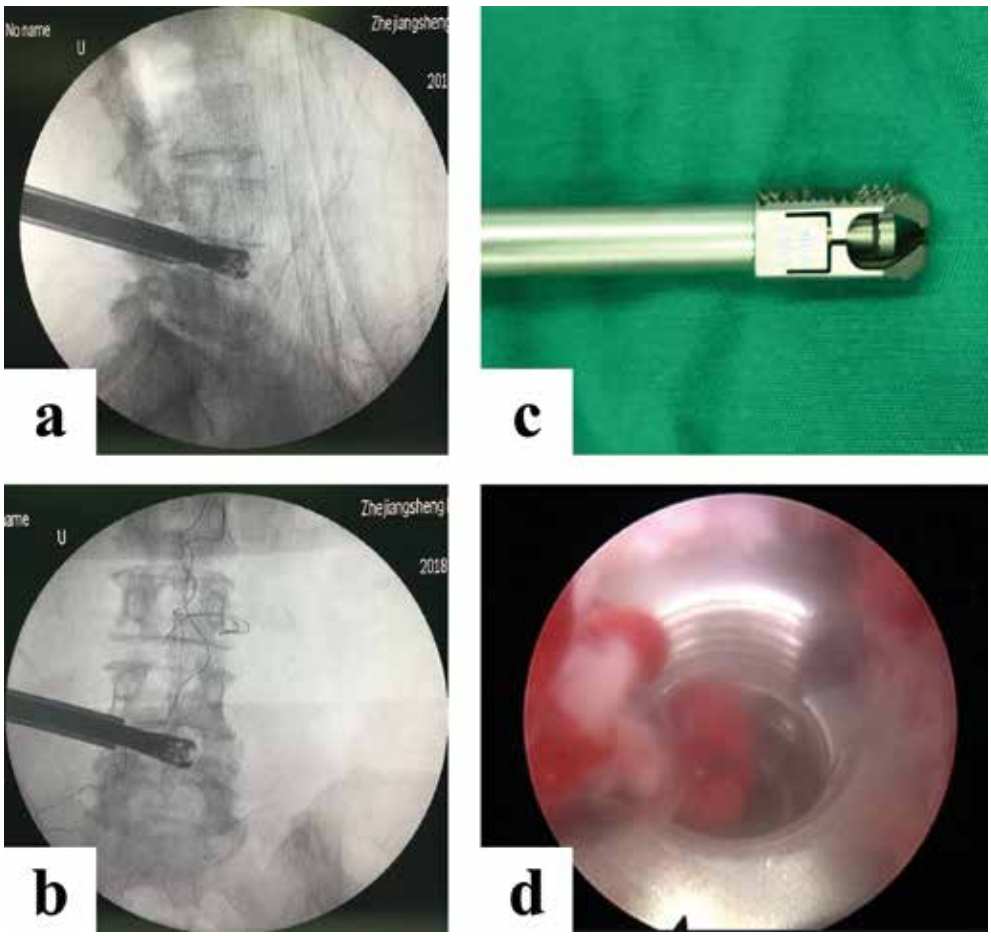

Fig. 3. *The cage is placed into the disc space under fluoroscopic guidance (A, B). The cage could be expanded to 12 to 13 mm of height when fixed (C). Inspect the disc space and ventral side of the dura under endoscopic visualization before withdrawing the working sheath (D).*

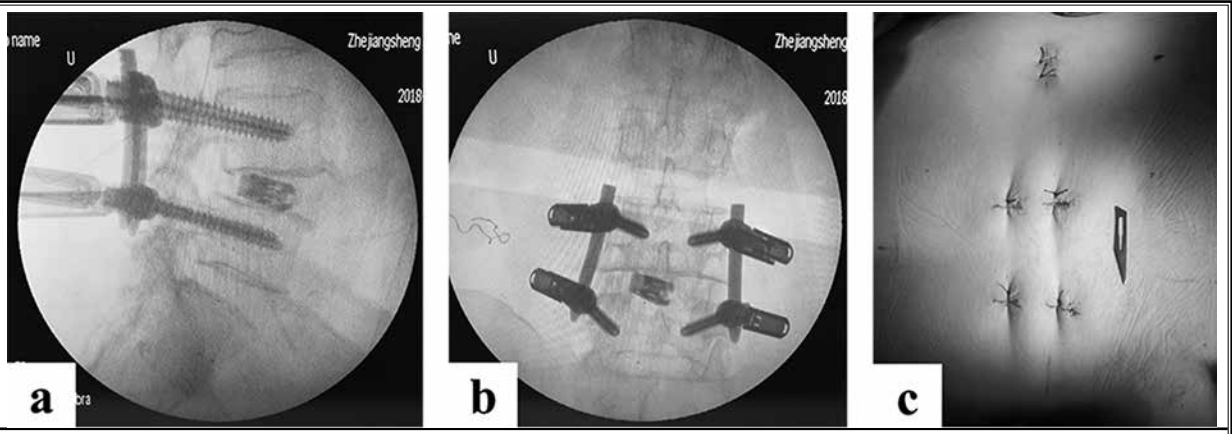

Fig. 4. *The pedicle screws are inserted, and 2 rods are attached to the screws subfascially (A, B). All 5 incisions were about 1 cm in length (C).*

Table 2. *Demographic and baseline characteristics of all patients.*

Characteristic	Value
Number of patients	39
Male	25
Female	14
Age in years	59.0 ± 9.9 (range, 39-77)
Etiology	
De novo disc herniation	35
Grade I spondylolisthesis	9
Combined	6
Recurrent disc herniation	1
Surgical level	
L2/3	1
L3/4	9
L4/5	26
L3/4 & L4/5	3
Left/Right	17/22
Operation time in minutes	213.8 ± 31.7 (range, 185-324)
Intraoperative blood loss in milliliters	25.0 ± 12.6 (range, 15-50)
Hospital length of stay in days	6.7 ± 0.9 (range, 5-11)
Follow-up duration in months	23.6 ± 4.9 (range, 17-28)

ated by the paired Student t test. All significance tests were 2-tailed, with $P < 0.05$ representing statistical significance.

Results

Thirty-nine (25 men and 14 women) patients, with a mean age of 59.0 ± 9.9 years (range, 39-77 years) were enrolled in the present study. The diagnoses were de novo disc herniation in 35 patients, grade 1 spondylolisthesis in 9 patients, both de nova and grade 1 spondylolisthesis occured in 6 patients and recurrent disc herniation in one patient. The procedures were performed on L2/3 in one case, L3/4 in 9 cases, L4/5 in 26 cases, and L3/4 with L4/5 in 3 cases. The mean follow-up duration was 23.6 months (range, 17-28 months). The average surgical time was 213.8 ± 31.7 minutes (range, 185-324 minutes). Mean estimated blood loss was 25.0 ± 12.6 mL (range, 15-50 mL). The mean hospital length of stay was 6.7 ± 0.9 days (range, 5-11 days) (Table 2). The mean preoperative VAS-B and VAS-L pain scores were 5.7 ± 0.8 and 7.9 ± 0.5, respectively, which were improved to 0.7 ± 0.2 and 1.0 ± 0.0 postoperatively. At the final follow-up visit, the mean VAS-B and VAS-L pain scores were 0.6 ± 0.5 and 0.4 ± 0.3 with 89.5% and 95.0% improvements from the preoperative period, respectively. The mean preoperative SF-36 Mental Component Summary (MCS) and Physical Component Summary (PCS) scores were 41.7 ± 5.1 and 34.2 ± 5.7, respectively, which were improved to 53.3 ± 8.7 and 49.8 ± 6.1 postoperatively. At the final follow-up visit, the mean SF-36 MCS and SF-36 PCS scores were 57.1 ± 6.6 and 54.2 ± 4.9 with 37.0% and 58.5% improvements from the preoperative period, respectively. The mean preoperative ODI score was 43.1 ± 4.9, which was improved to 16.1 ± 7.2 postoperatively and 12.4 ± 6.5 at the final follow-up visit (Table 3). The differences between the preoperative and postoperative values, including the last follow-up examination scores were statistically significant, so were those between preoperative values and values at the final follow-up.

The preoperative symptom was not relieved or even aggravated in 2 cases. Specifically, disc mass remnant was observed in one patient, and remedial PELD was performed 4 days after index surgery. Misplacement of L5 pedicle screw was observed in another patient, and the misplaced screw was removed 3 days after index surgery. Asymptomatic cage subsidence was observed in one case, of which the segmental stability was not jeopardized. No other perioperative complications, including dural tear, infection, or implant loosening occurred. According to the x-rays or CT scans, radiologic fusion was achieved in all cases because radiopaque graft in the disc space was observed in all cases at the final follow-up visit (Fig. 5).

Table 3. *Preoperative, postoperative, and the last follow-up VAS, ODI, and SF-36 scores.*

Characteristics	Preoperative	Postoperative	Follow-Up
VAS-B	5.7 ± 0.8	0.7 ± 0.2*	0.6 ± 0.5†
VAS-L	7.9 ± 0.5	1.0 ± 0.0*	0.4 ± 0.3†
ODI score	43.1 ± 4.9	16.1 ± 7.2*	12.4 ± 6.5†
SF-36 PCS	34.2 ± 5.7	49.8 ± 6.1*	54.2 ± 4.9†
SF-36 MCS	41.7 ± 5.1	53.3 ±8.7*	57.1 ± 6.6†

*The postoperative values were compared with preoperative values, and the results were statistically significant ($P < 0.05$).
†The follow-up values were compared with preoperative values, and the results were statistically significant ($P < 0.05$).

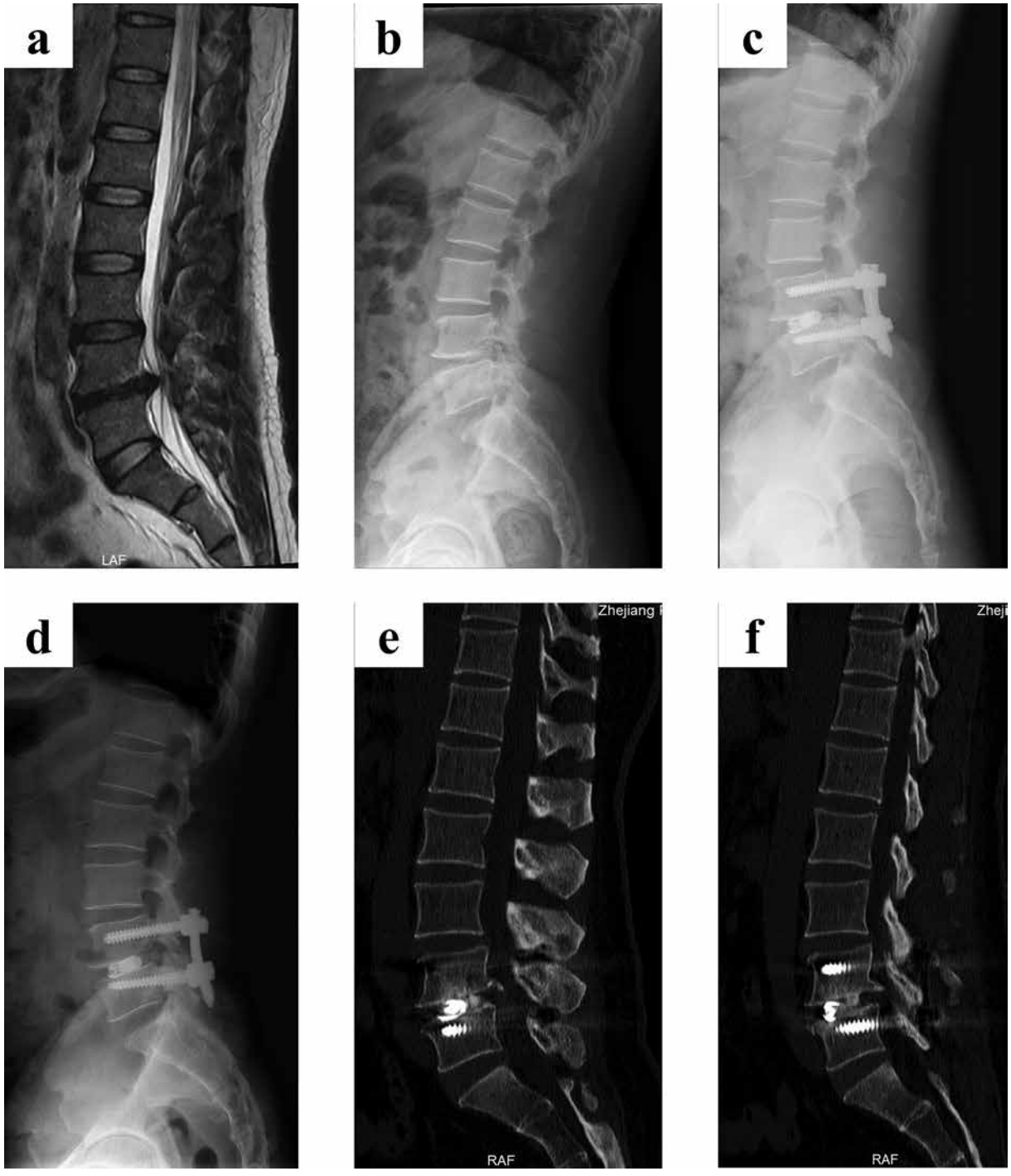

Fig. 5. *A 67-year-old man was admitted to our institution due to severe low back pain, right lower extremity pain and numbness for 2 months. Preoperative MRI and x-rays revealed severe disc collapse and herniation on the partial right side at L4/5 (A, B). Lateral radiograph at 3 (C) and 9 (D) months postoperatively. Sagittal CT images at 12 months (E) and 27 (F) months postoperatively revealed solid interbody fusion.*

Discussion

With the advent of revolutionary innovation in endoscopic apparatus and surgical techniques in the last decade, the treatment paradigm for degenerative lumbar disorders has shifted from open surgery to minimally invasive spine surgery. A variety of less traumatic procedures, such as minimally invasive transforaminal lumbar interbody fusion (MIS TLIF), ALIF, DLIF, and OLIF, could achieve the minimal invasive goals, including decreased blood loss, shorter hospital length of stay, and rapid recovery. Although these procedures share the label of "MISS," each of them has unique attributes in terms of surgical indication, disruption of the normal anatomic structures, and collateral damage to the neighboring structures, for example, an incision about 30 mm, splitting of paravertebral muscles, and excision of the facet joint are unavoidable when performing MIS TLIF (14).

The PELIF technique is a natural evolution of PELD surgery, which manipulates lumbar interbody fusion through a percutaneous transforaminal approach. Although the steps for disc instrumentation are fairly simple and straightforward, the limited triangular operating space over the posterolateral disc bordered by the traversing and exiting nerve roots, and hence the possibility of neural injury, has led to a low level of enthusiasm for this approach by spine surgeons until recent years (2). In the present study, we described the technique note of PELIF without general anesthesia, and shared clinical and radiologic results with mean 2-year follow-up.

Appropriate selection of patients and precise surgical indication of the procedure are decisive factors for promising results with PELIF. In our series, the surgical indications for using PELIF included de novo/recurrent disc herniation, segmental instability, or spondylolisthesis (no more than Meyerding grade II). The rationale for using PELIF should be stratified according to the patients' condition, including the geriatrics with grave comorbidities and a high operative risk with open surgery (15); and patients with imbalanced deformities who are not fit for conventional, state-of-the-art, extensive anterior and posterior fusion (5). Also, in young patients with anesthetic contraindications, declining a long hospital stay or massive trauma are in favor of PELIF. Moreover, PELIF might be a satisfactory remedy for patients with recurrent surgery and scars from a previous surgery (16).

Since Osman (2) reported the application of PELIF for the treatment of degenerative lumbar diseases in 2012, several case series studies have demonstrated the promising surgical outcomes of this technique (5-7,17). Great concerns have been laid on the following aspects: (1) whether posterior fixation is mandatory, (2) whether unexpandable cages are superior to expandable ones, and (3) whether solid fusion could be achieved. In 2013, Jacquot and Gastambide (5) reported the clinical and radiologic results of 57 patients treated with PELIF, and they had used stand-alone cages in 46 cases, and contemporary posterior fixation in 11 cases. The surgical outcomes were not promising as mentioned by themselves because cage migrations were observed among 15 cases, and 13 (22.8%) symptomatic cases accepted remedial operation. In the meantime, 8 patients suffered from postoperative paresis and painful syndromes. As they reported, in the remaining cases with no migration, fusion was obtained in all cases after a mean duration of 6 months (range, 3-12 months). We have speculated that the following aspects might result in the unsatisfactory outcomes, including insufficient preparation of the disc space because the mean surgical time was 60 minutes, calcium phosphate substitute filled in cages rather than autograft, and no autograft prefilled in the anterior and lateral recesses of the disc space before cage insertion. In another case series study conducted by Lee et al (17), stand-alone cages without posterior fixation were used in 18 patients, 16 of which achieved solid fusion. The differences were that they had sufficient disc space preparation and placed autogenous bone graft into the cage and disc space to facilitate the bone union. As they suggested, posterior pedicle screws or other posterior fixation methods might have been a better option to augment the PELIF surgery in one patient who received a remedial ALIF surgery with percutaneous pedicle screw fixation.

Morgenstern and Morgenstern (18) compared the surgical outcomes of patients with degenerative lumbar diseases who had received percutaneous transforaminal interbody fusion with either self-expandable or rigid interbody plant. The results demonstrated that the percutaneous expanded interbody implant with percutaneous posterior fixation (360° fusion) shows similar outcome than open or MIS TLIF surgery with rigid interbody implants and allows convenient distraction and reduction in cases of spondylolisthesis. Wu et al (7) performed PELIF with unexpandable cages in 7 patients, and they had agreed that the self-expandable cage design seemed to be a better option for the PELIF technique. Self-expandable cages with smaller initial size facilitates cage insertion and reduces possible neu-

rologic invasion. Moreover, expandable cages allow indirect neural decompression and additional foraminal expansion by restoring intervertebral height; immediate stability to the fixation construct is also enhanced. The results of the present study were in line with the earlier mentioned viewpoint, and provided supporting evidence of the superiority of the PELIF technique using self-expandable cages.

Disc space and end plate preparation are crucial for interbody fusion and avoidance of cage migration. During conventional open procedures, end plate preparation by reamer and curette is performed without direct visualization, and subchondral bone may be damaged in this blind step (19). Theoretically, performing end plate preparation under endoscopic visualization insures sufficient and adequate preparation, rather than relying on palpation with instruments (6). In the present study, asymptomatic cage migration was observed in one patient due to improper intraoperative manipulation of subchondral bone. As mentioned by many surgeons, a steep learning curve was a great obstacle of the PELIF technique. This technical error occurred during the early phase of the present study, which was avoided in the following period as the surgeon gained more experience.

As a new-emerging, high-demanding, and controversial procedure, PELIF techniques were described nonuniformly by only a few preliminary retrospective and uncontrolled studies. According to the aforementioned data and our preliminary experience, sufficient and adequate disc space preparation, use of autogenous bone instead of allograft, and complementary posterior fixation are key factors for the successful implementation of the PELIF technique. Despite the aforementioned benefits, the PELIF technique does has several shortcomings, including a steep learning curve, relatively high dose of irradiation, and relatively strict surgical indications. For example, the L5/S1 approach is a relative exclusion considering that the iliac crest may obstruct the cage insertion. Moreover, the presented results are preliminary and should be interpreted considering the limitations, including nonrandomized design, relatively small sample size, and less intensive follow-up period. However, these patients are followed up regularly, and studies are undertaken to clarify the long-term clinical and radiologic results of this promising technique.

Conclusions

The satisfactory clinical and radiologic results demonstrate that the PELIF technique seems to be a promising surgical technique for treating specific patients with or without disc herniation and instability, and mild degenerative spondylolisthesis. We do believe that as the surgical apparatus improves and surgeons become proficient in these procedures, the PELIF technique will gain widespread popularity for its minimally invasive superiorities, including minimized neuromuscular trauma and anesthesia risk, shorter hospital length of stay, and accelerated recovery program. A prospective, randomized study with a larger sample size should be undertaken to prove the superiority of this versatile technique.

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