Early Clinical Results of Percutaneous Endoscopic Transforaminal Lumbar Interbody Fusion: A New Modified Technique For Treating Degenerative Lumbar Spondylolisthesis

Names of all authors

Ken Nagahama1,*, Manabu Ito2, Yuichiro Abe3, Eihiro Murota1, Shigeto Hiratsuka1, Masahiko Takahata4

Institutional affiliations

1 Department of Orthopaedic surgery, WajokaiSapporo Hospital, Japan

2 Department of Orthopaedic surgery, Kokuritsu Hospital Kiko Hokkaido Medical Care Center, Japan

3 Department of Orthopaedic surgery, Wajokai Eniwa Hospital, Japan

4 Department of Orthopaedic surgery, Hokkaido University Hospital, Japan

Corresponding author

Ken Nagahama

3-7, Kita-24, Higashi-1, Higashi-ku, Sapporo, Hokkaido, Japan

Telephone: +81-11-753-3030

Fax: +81-11-753-1333

E-mail: k.nagahama.8@gmail.com

Conflicts of Interest:

None declared
Source of financial support:

None declared

Type of contribution of authors:

None declared

Approval code:

This study was approved by the ethical committee for clinical research at Wajokai Sapporoa Hospital (Approval number: 2017-1, Approval date: February 3, 2017).

The submission is seen, reviewed, and approved by all contributing authors.

Acknowledgments:

We would like to thank Editage (www.editage.com) for English language editing and Publication Support.

Disclaimer:

Manabu Ito is the Editor of Spine Surgery and Related Research and on the journal's Editorial Committee. He was not involved in the editorial evaluation or decision to accept this article for publication.
Early Clinical Results of Percutaneous Endoscopic Transforaminal Lumbar Interbody Fusion: A New Modified Technique for Treating Degenerative Lumbar Spondylolisthesis

Abstract

Background: Lumbar interbody fusion is used to treat degenerative lumbar spondylolisthesis with instability. We developed a device that safely expands a percutaneous path through Kambin’s Triangle and used it via a new technique: percutaneous endoscopic transforaminal lumbar interbody fusion (PETLIF). We report in this study the details and outcomes of this procedure after a one-year follow-up.

Methods: Twenty-five patients requiring interbody fusion for degenerative spondylolisthesis of the L4 vertebra were enrolled in this study. The procedure involved percutaneous posterior pedicle screw placement to correct spondylolisthesis. After the exterior of the L5 vertebra superior articular protrusion was shaved with a percutaneous endoscopic drill in order to expand the safe zone, the oval sleeve was inserted through Kambin’s Triangle and was rotated to expand the disk height and create a path towards the vertebral disk. The interbody cage was inserted against the J-shaped nerve retractor, with the exiting nerve root retracted. Indirect decompression of spinal canal stenosis was expected because the vertebral body spondylolisthesis had been corrected, and the interbody distance was expanded. Thus, no direct decompression was
performed posterolaterally.

**Results:** The mean follow-up period, surgery time, and blood loss were 22.7 months, 125.4 min, and 64.8 mL, respectively. The Japanese Orthopedic Association score improved from 13.3 to 28.0. The Roland-Morris Disability Questionnaire score improved from 10.3 to 3.3. All items were evaluated both preoperatively and one-year postoperatively. Bone fusion was observed one year postoperatively in 22 out of 25 patients.

**Conclusions:** These results demonstrate the feasibility and efficacy of PETLIF for treating degenerative lumbar spondylolisthesis. This minimally invasive procedure is useful and has wide applicability. To obtain safe and favorable results, necessary surgical techniques must be mastered, and surgical equipment, including that for neural monitoring, is required.

**Key Words**

Percutaneous endoscopic surgery; Lumbar interbody fusion; Degenerative lumbar spondylolisthesis; New surgical technique
Introduction

Degenerative lumbar spondylolisthesis involves symptoms resulting from anteroposterior spondylolisthesis of the lumbar vertebrae occurring because of aging-associated degeneration\(^1\). Degenerative spondylolisthesis usually occurs at the L4 level\(^2,3\). It occurs in approximately 10% of women aged $\geq 60$ years\(^4\). Following conservative management, surgery is an option and has an established efficacy\(^5\). Lumbar interbody fusion is performed in cases with high instability, and the mainstream methods include posterior lumbar interbody fusion (PLIF), as reported in the study by Cloward et al. in 1953\(^6\), and transforaminal LIF (TLIF), as reported in the study by Harms et al. in 1982\(^7\). As spinal surgery progressed, TLIF became less invasive.

Minimally invasive TLIF (MIS-TLIF), which includes fusion of vertebrae using percutaneous pedicle screws (PPS), was first reported in the study by Foley et al. in 2001\(^8\). It became a popular procedure, causing a shift toward less invasive surgery. Many studies have shown that MIS-TLIF is less invasive, involves less blood loss, has a shorter recovery time, and requires fewer days in the hospital by comparison with open TLIF\(^9-12\). However, in addition to MIS-TLIF, partial laminectomy, facetectomy, and ligament flavum dissection, an open incision of the musculature, are required to reach the vertebrae.

If the vertebrae are approached posterolaterally via Kambin’s Triangle, invasive procedures can be avoided\(^13,14\). This is a standard route in percutaneous endoscopic discectomy
If this path can be sufficiently expanded to allow for the passage of an interbody cage of the size used in open TLIF, it may be possible to apply LIF while completely preserving the joint facet. In this study, we developed a surgical device comprising an oval dilator, oval sleeve, and a J-shaped nerve retractor. This device is capable of securing a percutaneous path large enough to safely insert an interbody cage. We also conceived a new technique, percutaneous endoscopic TLIF (PETLIF). To our knowledge, this is the first report on PETLIF in the treatment of degenerative lumbar spondylolisthesis with instability, using a cage size similar to that used in TLIF. We describe here the early clinical results of this new technique.

Materials and Methods

Patients

Twenty-five patients with lumbar degenerative spondylolisthesis (five men, 20 women; mean age, 68.4 years, standard deviation [SD], 9.1 years) underwent PETLIF at our institution between February 2016 and July 2018. The mean follow-up period was 22.7 (range, 12-30) months. These patients were also diagnosed at our institution. All patients were preoperatively informed about the characteristics, difficulty, and potential complications of the procedure. Written informed consent was obtained from all patients prior to commencement of the study. The study was approved by the ethics committee for clinical research at our institution.
Inclusion criteria

We included patients who were diagnosed with degenerative lumbar spondylolisthesis at the L4 level, with lumbar pain and radicular symptoms caused by intervertebral instability that was associated with spinal canal stenosis. All patients were refractory to conservative treatment and required interbody fusion. Imaging was performed using functional radiography, computed tomography (CT), and magnetic resonance imaging (MRI). Instability was diagnosed if the vertebral slippage was $\geq 4$ mm or if the mobility in flexion or extension was $\geq 10^\circ$.

Evaluation method

The following metrics were used to evaluate the surgery: surgical time; volume of intraoperative blood loss; and volume of postoperative drainage. To evaluate functions before surgery, at hospital discharge, six months, and one year after surgery, we utilized the Japanese Orthopedic Association (JOA) criteria and the Roland-Morris Disability Questionnaire (RDQ) score to assess the treatment outcomes of patients. The presence or absence of bone fusion was ascertained with CT scans one year postoperatively.
Surgery was conducted under general anesthesia, with the patient in the prone position.

The somatosensory-evoked potentials, electromyography, and free-run electromyography were monitored throughout the procedure using a nerve monitoring system (NVM5®; Nuvasive, San Diego, USA).

Posterior pedicle screw fixation and spondylolisthesis correction

Firstly, all patients underwent posterior PPS fixation using the IBIS Spinal System® (Japan Medical Dynamic Marketing, Tokyo, Japan). A screw, with diameter of 6.5 mm and length of 40 mm, was then inserted under fluoroscopic guidance. Regarding rod positioning, the L5 set screw was fixed, while the L4 side of the rod was floated (Fig. 1A). The spondylolisthesis of the L4 vertebra was then corrected by tightening the L4 set screw (Fig. 1B).

Expansion of Kambin’s triangle

The Spine TIP® transforaminal approach kit (Karl Storz GmbH, Tuttingen, Germany) endoscopic system was used. To reduce the risk of damaging the exiting nerve root while inserting the cage, the outside of the L5 vertebra superior articular protrusion was shaved using a burr (Nakanishi Primado2® total surgical system, Tochigi, Japan) using fluoroscopy and percutaneous endoscopy (Figs. 1C, D).
Harvesting bone for grafting

Bones from the ilium and spinous process were used for grafting and were harvested percutaneously. In the cage, the only filling was local bone, whereas a mixture of local and artificial bone (hydroxyapatite and tripotassium phosphate composite; Primabone® granule size M; 5 g; Japan Medical Dynamic Marketing, Tokyo, Japan) was used for the interbody graft.

Creating a percutaneous path, expanding the interbody distance, and preparing the graft site

New oval dilator, oval sleeve, and J-shaped nerve retractors (Robert Reid Inc., Tokyo, Japan) were used (Figs. 2A, B). After inserting the oval dilator, the oval sleeve, which has a long (10.5 mm) and a short axis (8 mm; outer dimensions), was inserted with the 8-mm cephalocaudal axis. Next, the L5-side set screw of the fixed PPS system was loosened, the oval sleeve was rotated 90 ° (Fig. 3A), and the interbody distance was expanded to 10.5 mm, which was the length of the longer axis of the oval sleeve (Fig. 3B). The disk was excised via the oval sleeve using curettes and vertebral pulp forceps (Figs. 3C, D).

Positioning the cage

Graft bone was introduced into the intervertebral space via the oval sleeve (Fig. 4A).
Next, a specially designed J-shaped nerve retractor (Robert Reid Inc., Tokyo, Japan) was inserted into the oval sleeve and the oval sleeve was withdrawn. To prevent the exiting nerve root from accidentally encroaching upon the cage insertion route, the J-shaped nerve retractor was kept in the intervertebral space. With the exiting nerve root retracted, the interbody cage was inserted against the J-shaped nerve retractor (Figs. 4B, C). The cage was chosen to match the patient’s anatomy and form of his or her vertebral body. A ReyKam® cage (Robert Reid Inc., Tokyo, Japan), measuring 30x12x9 mm, was inserted in this case (Fig. 4D).

 Completion of interbody fusion and post-surgery management

Compression was exerted between the vertebral bodies to ensure final bonding (Fig. 4E). The Elliquence Trigger-Flex® bipolar system (Surgi-Max Air, New York, USA) was used to stop any bleeding under percutaneous endoscopic guidance. Finally, a tube drain was installed at the cage insertion site. Regarding the procedure’s impact on spinal canal stenosis, indirect decompression was expected because the vertebral body spondylolisthesis was corrected, and the interbody distance was expanded. Consequently, direct decompression was not performed posterolaterally. The patients’ activities of daily living were not restricted.

Statistical Methods
Continuous variables are presented as mean (SD). Statistical differences were determined using a two-sided paired t-test. All p-values <0.05 were considered significant.

Microsoft Excel software (Microsoft, Redmond, WA) was used for analysis.

Results

The mean surgical time, blood loss, and post-surgery drain volume were 125.4 (56.9) min, 64.8 (35.6) mL, and 32.5 (28.6) mL, respectively. Complications occurred in two patients who exhibited a reduction in hip flexion power immediately after surgery that was completely resolved within two weeks. One patient required additional surgery. Although his progress was good after surgery, neural symptoms flared up again one month after surgery because the cage subsided. Posterior decompression was required. The cause was determined to be low compatibility between the surface of the cage and the vertebral body endplate, because the insertion of the cage was rotated about 30° and sinking occurred at an early stage.

The JOA score improved from 13.3 (2.09) preoperatively to 24.9 (1.85; p < 0.001) at discharge, 25.7 (1.43; p < 0.001) six months postoperatively, and 27.3 (1.18; p < 0.001) one year postoperatively. The RDQ score improved from 10.3 (4.56) preoperatively to 10.1 (4.09; p = 0.902) at discharge, 4.8 (2.73; p = 0.002) six months postoperatively, and 3.7 (3.50; p = 0.001) one year postoperatively. One-year postoperatively, bone fusion was observed in 22 of the 25
patients. There were no cases of screw loosening.

Case report

Using imaging, a 67-year-old woman was diagnosed as having degenerative spondylolisthesis of the L4 vertebra with instability (Figs. 5A, B). PETLIF was performed (Fig. 5C). At the time of hospital discharge, the patient’s lumbar and leg pain had disappeared. Postoperative MRI revealed that her spinal canal had expanded by 176% due to indirect decompression (Fig. 5D).

Discussion

LIF via Kambin’s Triangle is a type of MIS-TLIF, which is a microendoscopy-assisted surgery that uses a small incision. Recently, a less invasive percutaneous LIF technique via Kambin’s Triangle has also been reported18-20). These procedures are divided into two categories, according to the method of cage insertion. In one category, the cage is inserted via a sleeve, as used in the PED procedure; while in the other, insertion is guided by percutaneous imaging. The former category is safer because cage insertion is completed via a sleeve using PED techniques, but there is a limit to the cage size. To overcome this, an expansion maneuver was recently performed after the insertion of the cage between the vertebrae. After discectomy and preparation of the graft site using PED techniques, Wang et al.18) in their study inserted a mesh
expandable cage (Spineology’s OptiMesh® graft containment, CA, USA) from within a sleeve. This enabled them to safely introduce grafted bone to the intervertebral disk space, but the strength of fixation remained lower than that of a cage inserted using open techniques. The second category enables strong fixation because an ordinary sized cage is used, similar to that used in TLIF. However, there is a risk of damage to the exiting nerve root when the cage is inserted. Abbasi et al.\textsuperscript{19)} in their study inserted a guidewire in the middle of the disk from Kambin’s Triangle and prepared the graft site and inserted the cage via that guidewire. To avoid damage to the exiting nerve root, they used a cage that was shaped to facilitate its avoidance of the exiting nerve. However, the nerve was shielded by the cage body during insertion and was not retracted with a nerve retractor or similar device. PETLIF is a technique in which the graft site is prepared within a sleeve and a standard-size cage is inserted, while the exiting nerve root is completely avoided with a J-shaped nerve retractor, implying that the procedure is safe and facilitates strong fixation. PETLIF can expand Kambin’s Triangle because the risk of damage to the exiting nerve root decreases. Percutaneous LIF via Kambin’s Triangle is often indicated for patients with degenerative disk disease\textsuperscript{18,19). However, for patients with degenerative spondylolisthesis and reduced interbody height, there is an increased risk of damage to the exiting nerve root because of the narrowing of Kambin’s Triangle. With the PETLIF procedure, Kambin’s Triangle is
expanded owing to the correction of the spondylolisthesis of the vertebral body using PPS, and
the expansion of the interbody height using the oval sleeve. Further, to increase safety, the
outside of the L5 vertebra superior articular protrusion is shaved with the help of a percutaneous
endoscope and the original Kambin’s Triangle is widened. The cage size is decided based on the
position of the exiting nerve, shape of the L5 superior articular process, and height of the
interbody using preoperative radiographical assessment (Fig. 6). If the exiting nerve path is
anterior, then the safety margin at insertion is wide, and the insertion of a larger cage with a
12-mm diameter becomes possible. In terms of cage height, it is possible to insert a cage with a
maximum height of 12 mm in cases with naturally high disk heights, as the safety margin on the
caudal side of the Kambin’s Triangle widens.

Recently, surgeons have utilized minimally invasive lateral LIF (LLIF) techniques, such
as oblique LIF and eXtreme lateral interbody fusion\textsuperscript{20-22}. However, with LLIF, there are issues
with the insertion path, along with associated damage to major blood vessels, somatic arteries,
the greater psoas muscle, lumbar plexus, urinary duct, or internal organs\textsuperscript{23-25}. Although the
posterolateral route via Kambin’s Triangle involves risk of damage to the exiting nerve root,
once this is avoided, no risk of complications can arise with use of LLIF. Furthermore, unlike the
cage in LLIF, the cage in PETLIF can be inserted in the same position from either the left or
right side. For example, in cases of degenerative scoliosis, the interbody cage can be inserted
from the convex side with a wider safety zone. With the LLIF procedure, an indirect decompression effect on degenerative spondylolisthesis has been reported, which does not require direct surgery on the nerve tissue or on the epidural venous plexus\textsuperscript{26-29)}. With PETLIF, an improvement in preoperative radicular symptoms was recognized in all cases due to indirect decompression following the insertion of a cage with height of 9 or 10 mm and correction of vertebral body spondylolisthesis using PPS.

Limitation

The first limitation of this study is that PETLIF use assumes that a cage can be inserted from a widened Kambin’s Triangle, and it is essential to be aware of the increased risk associated with the expansion of the interbody height or the increased risk if the correction of vertebral body spondylolisthesis during surgery is insufficient. In our hospital, we halt any procedure in which nerve monitoring alerts us regarding concerning stress levels on the nerve root, subsequently prompting us to switch to open surgery using TLIF. The possibility of this happening was explained to patients before surgery and their consent was obtained. In this series, two cases were converted to open TLIF. The reason for conversion was that there was insufficient reduction of spondylolisthesis of the L4. It is important to conduct a thorough preoperative radiographical assessment to ascertain if reduction of the spondylolisthesis is
possible. We plan to discuss the dividing line between the indicators of TLIF and PETLIF in a future study.

Another limitation of this study was the small number of cases involved, while the third limitation was that it was not a randomized controlled study. Without comparisons to other surgical methods, the utility of PETLIF cannot be accurately judged. However, we plan to conduct a comparison between PETLIF and existing surgical techniques in the next stage.

Conclusion

This study described a new modified technique, PETLIF, for treatment of degenerative lumbar spondylolisthesis, and also evaluated relevant early clinical results. Intervertebral fusion surgery using Kambin’s Triangle is a less-invasive procedure, but the risk of damaging the exiting nerve root is an important problem. The safety margin can be increased by enlarging Kambin’s Triangle under percutaneous endoscopy. To obtain safe and favorable results, proficiency in surgical techniques involved is required, as well as in terms of surgical equipment, including equipment needed for neural monitoring. This procedure is highly applicable for minimally invasive interbody fusion.
1 References


29. Oliveira L, Marchi L, Coutinho E, et al. A radiographic assessment of the ability of the
extreme lateral interbody fusion procedure to indirectly decompress the neural elements.

Figure Legends:

Fig. 1  A: With the L4 side of the rod loose (black arrow), the L5 set screw was fixed; B: Correction of the L4 vertebral body spondylolisthesis occurred as the vertebral body and the percutaneous pedicle screws were drawn to the rod; the white line on the back of the vertebral body is almost straight. C: The position of the drill tip was confirmed using imaging (the area encircled by the white dotted line); D: Image showing shaving of the L5 vertebra superior articular protrusion with a drill, using endoscopy.

Fig. 2. A: The images in order from top to bottom are of an oval dilator, oval sleeve, and a J-shaped nerve retractor (Robert Reid Inc., Tokyo, Japan). B: The left image is of the oval sleeve for percutaneous endoscopic discectomy, and the right image is of the elliptical sleeve for percutaneous endoscopic transforaminal lumbar interbody fusion. The short axis was set as the same size.

Fig. 3 A: The elliptical operating sheath was inserted with the shorter axis cephalocaudal and rotated (in the direction of the black arrow); B: The rotation expanded the interbody distance to 10.5 mm, which was also the length of the longer axis of the operating sheath (black arrow). C and D: A ring curette and vertebral pulp forceps were inserted using a percutaneous endoscopic
transforaminal lumbar interbody fusion operating sheath.

Fig. 4. A: The graft bone was introduced into the intervertebral space via the oval sleeve; B and C: The tip of the J-retractor was kept in the intervertebral disk space to prevent the exiting nerve root from straying into the cage entry path and the cage was inserted along the J-shaped nerve retractor; D: The cage was positioned in the intervertebral space; E: The final task was compression between the vertebral bodies.

Fig. 5 A: A patient with degenerative changes surrounding the L4/5 facet and anterior spondylolisthesis of L4; B: Functional imaging shows intervertebral mobility of 17° and spondylolisthesis of 4 mm; C: X-ray of the lumbar vertebrae immediately after surgery; D: Left, preoperative axial magnetic resonance image (MRI); right, postoperative axial MRI; the spinal canal was expanded from 55.7 mm² to 92.6 mm².

Fig. 6 The cage location, confirmed with a multimodality fusion image (the white dotted circle marks the insertion position).
Fig. 1 A: With the L4 side of the rod loose (black arrow), the L5 set screw was fixed; B: Correction of the L4 vertebral body spondylolisthesis occurred as the vertebral body and the percutaneous pedicle screws were drawn to the rod; the white line on the back of the vertebral body is almost straight. C: The position of the drill tip was confirmed using imaging (the area encircled by the white dotted line); D: Image showing shaving of the L5 vertebra superior articular protrusion with a drill, using endoscopy.

90x95mm (300 x 300 DPI)
Fig. 2. A: The images in order from top to bottom are oval dilator, oval sleeve, and J-shaped nerve retractor (Robert Reid Inc., Tokyo, Japan). B: The left image is the oval sleeve for the PED procedure, and the right image is the elliptical sleeve for PETLIF. The short axis was set as the same size.
Fig. 3 A: The elliptical operating sheath was inserted with the shorter axis cephalocaudal and rotated (in the direction of the black arrow); B: The rotation expanded the interbody distance to 10.5 mm, which was the length of the longer axis of the operating sheath (black arrow). C and D: A ring curette and vertebral pulp forceps were inserted using a percutaneous endoscopic transforaminal lumbar interbody fusion operating sheath.
Fig. 4. A: The graft bone was introduced into the intervertebral space via the oval sleeve; B and C: The tip of the J-retractor was kept in the intervertebral disc space to prevent the exiting nerve root from straying into the cage entry path and the cage was inserted along the J-shaped nerve retractor; D: The cage was positioned in the intervertebral space; E: The final task was compression between the vertebral bodies.
Fig. 5. A: A patient with degenerative changes surrounding the L4/5 facet and anterior spondylolisthesis of L4; B: Functional imaging shows intervertebral mobility of 17° and 4-mm spondylolisthesis; C: X-ray of the lumbar vertebrae immediately after surgery; D: Left, preoperative axial magnetic resonance image (MRI); right, postoperative axial MRI; the spinal canal was expanded from 55.7 mm² to 92.6 mm².
Fig. 6. The cage location, confirmed with a multimodality fusion image (the white dotted circle marks the insertion position).