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CASE REPORT

Percutaneous endoscopic lumbar discectomy for high-grade down-migrated disc using a trans-facet process and pedicle-complex approach: a technical case series

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Abstract
Purpose The use of conventional percutaneous endoscopic lumbar discectomy (PELD) for high-grade down-migrated lumbar disc herniation medial to the pedicle via the transforaminal route can result in less favorable outcomes. We report a new PELD technique for the treatment of high-grade down-migrated lumbar disc herniation via a facet process and pedicle-complex approach.
Methods Three patients with high-grade down-migrated L3–4 and L4–5 disc herniation presented to our hospital. Each underwent PELD via a facet process and pedicle complex approach to remove the herniated fragment and achieve complete decompression of the nerve root.
Results Patients' symptoms were relieved. Postoperative magnetic resonance imaging showed root decompression. Follow-up 12-month computed tomography revealed no pedicle or facet fracture and healing of the pedicle complex and facet process bone tunnel.
Conclusion PELD via a facet process and pedicle-complex approach may be an option for high-grade, down-migrated lumbar disc herniation with completely sequestrated nucleus pulposus.

Keywords Lumbar disc herniation · High-grade down-migration · Percutaneous endoscopic lumbar discectomy (PELD) · Facet process · Pedicle complex

Introduction

Pioneers in spinal endoscopic surgery, such as Hijikata, Kambin, Yeung, Hoogland, Ruetten, and others, have developed various techniques for the treatment of lumbar disc herniation that minimize damage to the musculoskeletal and neural structures and speed both recovery and return to daily activities [1–6]. Ruetten et al. [7, 8] performed a randomized controlled study of totally endoscopic interlaminar and transforaminal lumbar discectomy versus conventional microsurgical technique for lumbar disc herniation. They concluded that these two surgical techniques exhibit similar clinical therapeutic effects and that the totally endoscopic procedure resulted in a smaller epidural scar and smaller wound at the surgical site and can be used for treatment of recurrent lumbar disc herniation. Endoscopic procedures have become the standard for many pathologies. The most widely used endoscopic procedure in patients with lumbar disc disease is transforaminal surgery [3, 4, 9]. With greater experience on the part of surgeons and with advances in endoscopic decompression techniques, selecting a percutaneous transforaminal or interlaminar endoscopic lumbar discectomy (TfELD or PiELD) has been adapted not only to central disc herniation, but also to high-grade migration such as inferior migration lower than the middle pedicle of the lower vertebra, trans-ligamentous and completely sequestrated types, which are known to be very difficult to remove [4–6]. The interlaminar spaces at L4–5 or higher are smaller in Asians than in Europeans and Americans, most Chinese surgeons perform endoscopic discectomy through the intervertebral foramina via a posterolateral approach. For endoscopic discectomy via the interlaminar spaces, part of the lamina should be removed, and the bone tunnel should be expanded using a high-speed endoscopic drill system, but because of its high cost, this type of endoscopic drill system

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is not yet available in most hospitals in China. In this study, we present a new technique, "percutaneous endoscopic lumbar discectomy (PELD) via a facet process and pedicle-complex (trans-facet–pedicle) approach", for the treatment of high-grade down-migrated L3–4 and L4–5 disc herniation.

Case reports

Case 1

A 67-year-old man presented with a complaint of severe radicular pain in the left gluteal region, anterolateral aspect of his left thigh, and anterior aspect of his left lower leg that had persisted despite pain medication with non-steroidal anti-inflammatory drugs for 2 months. Prior to admission, he had received conservative treatment at another hospital but declined further conservative treatment, such as epidural injection and transforaminal nerve root block, because of severe pain. On physical examination, a straight-leg raise test was positive at 50° on the left side. There was objective weakness of the left-side patellar tendon reflex. Magnetic resonance imaging (MRI) of the lumbar spine revealed extreme downward migration of the L3–4 disc, which was compressing the L4 root (Fig. 1a). Computed tomography (CT) scan showed soft disc herniation without calcification. A dynamic lateral-projection lumbar spine radiograph showed no instability of the L3–4 disc space. We performed posterolateral percutaneous endoscopic lumbar discectomy (PELD) via a facet process and pedicle-complex approach. Intraoperative fluoroscopy revealed the oblique caudal direction of the trephine to be from the superolateral to the inferomedial margin of the ipsilateral pedicle on orthogonal anteroposterior view (Fig. 1c–e). The migrated disc material was removed in one piece (Fig. 1f) and the L4 nerve root was successfully decompressed and the result was confirmed on postoperative MRI (Fig. 1b). A tunnel made through the facet process and pedicle complex could be seen on a three-dimensional 3D CT scan (Fig. 1g, h). CT obtained 10 months postoperatively revealed complete healing of the bone tunnel in the facet process and pedicle complex (Fig. 1i, j). The patient achieved a good outcome and visual analogue scale (VAS) score for leg pain and Oswestry Disability Index (ODI) improved from 6 points and 55% preoperatively to 0 points and 4%, respectively, at the 12-month follow-up.

Case 2

A 60-year-old man complained of pain in his low back and the posterolateral aspect of his right thigh and calf. The patient's symptoms did not improve after conservative treatment, including 6 weeks of medication and physiotherapy.

Fig. 1 T2-weighed magnetic resonance (MR) images in the axial plane along with topogram of the same patient showing downward migration of the herniated disc compressing the left L4 nerve root preoperatively (**a**) and removal of the down-migrated disc fragment postoperatively (**b**). Fluoroscopic images showing the position of the tip of the K-wire anchored in the facet process and pedicle complex in the lateral view and slight downward inclination of the K-wire from the superolateral to the inferomedial margin of the ipsilateral pedicle on anterolateral view (**c**). The trephine is advanced slowly over the K-wire in an inferomedial direction toward the herniated disc (**d**). Fluoroscopic images showing position of the working cannula and slight downward inclination from the superolateral to the inferomedial margin of the ipsilateral pedicle on anterolateral view, with the tip of the working cannula located at the posterior vertebral line in the lateral projection (**e**). Material from the migrated disc material was removed in one piece and circular bone was trephined (**f**). Postoperative 3D CT image shows the tunnel (white arrow) made through the L4 left facet process and pedicle complex (**g**). Postoperative CT image in axial view, sagittal and coronal views show the tunnel (white arrow) (**h**). Ten-month 3D CT image shows healing of the bone tunnels in the L4 left facet process and pedicle complex (white arrow) (**i**). Ten-month-postoperative CT image in axial view, sagittal and coronal views show the healing of the bone tunnel (white arrow) (**j**). 3D CT three-dimensional computed tomography

Prior to admission, he had received conservative treatment at another hospital. After admission, he did not want to continue conservative treatment because of severe pain. A straight-leg raise was positive at 30° on the right side. There was objective 4/5 weakness with dorsiflexion of the right great toe. MRI showed extreme down-migration of disc material at L4–5 (Fig. 2a). CT scan showed soft disc herniation without calcification. A dynamic lateral-projection lumbar spine radiograph showed no instability of the L4–5 disc space. Intraoperative fluoroscopy revealed the oblique caudal direction of the trephine to be from the superolateral to the inferomedial margin of the ipsilateral pedicle on orthogonal anteroposterior view (Fig. 2c, d). The endoscope was introduced via a predetermined entry point and inclination angle (Fig. 2e). The migrated disc material was removed (Fig. 2f) and the nerve root was exposed. Postoperative MRI showed the no evidence of the disc material (Fig. 2b), and postoperative 3D CT scan showed the bone tunnel through the facet process and pedicle complex (Fig. 2g, h). CT obtained 12 months postoperatively revealed partial healing of the bone tunnel of the facet process and pedicle complex (Fig. 2i, j). The patient achieved a good outcome, and VAS score for leg pain and ODI improved from 9 points and 71% preoperatively to 1 pint and 3%, respectively, at 12-month follow-up.

Case 3

A 45-year-old man complained of the severe radicular pain in the left leg along the L5 dermatome. He also complained

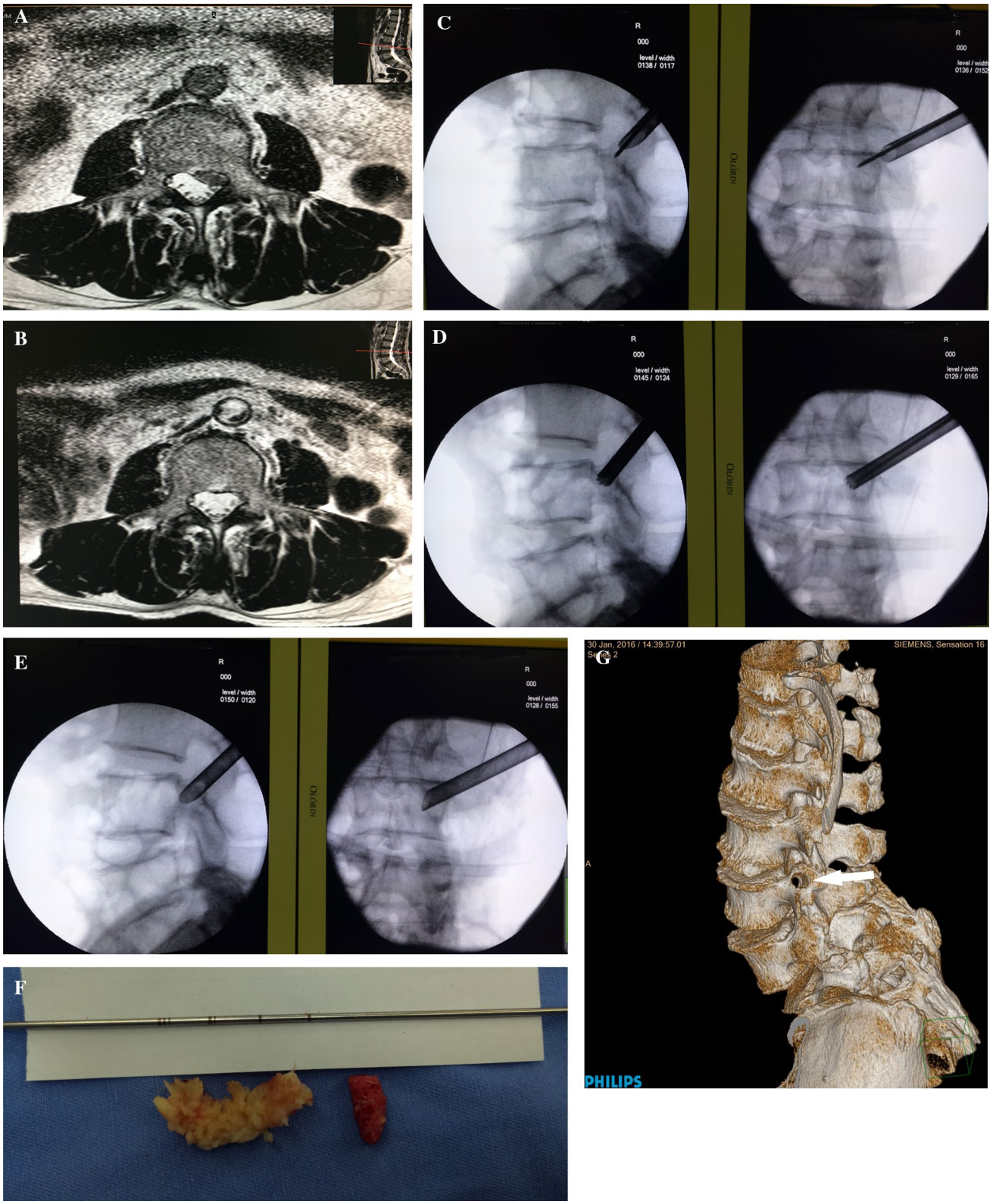
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Fig. 1 (continued)

of numbness and tingling of the anterolateral aspect of his right leg.

Physical examination demonstrated a positive straight-leg raise test at 30° on the left side. There was 2/5 weakness of dorsiflexion of the left great toe. The patient had no fasciculation, muscle atrophy, or upper motor neuron signs. MRI showed an extremely inferiorly migrated fragment of the L4–5 disc (Fig. 3a). A dynamic lateral-projection lumbar spine radiograph showed no instability of the L4–5 disc space. The patient's symptoms did not improve after conservative treatment, including 6 weeks of medication and physiotherapy. After admission, he chose not to undergo further conservative treatment because of severe pain. After the proper insertion of a working cannula (Fig. 3c, d), we performed a posterolateral PELD via a facet process and pedicle-complex approach. The L5 nerve root was successfully decompressed in the endoscopic view and the result was confirmed on postoperative MRI (Fig. 3b). Postoperative 3D CT scan showed the bone tunnel through the facet process and pedicle complex (Fig. 3e, f). VAS score for leg pain and ODI improved from 7 points and 65% preoperatively to 1 point and 6%, respectively, at 2-month follow-up.

Surgical technique

The patient is positioned in lateral decubitus position, with the symptomatic side up, on a radiolucent operating table. C-arm fluoroscopy was employed. The procedure is performed under local anesthesia (0.5% lidocaine solution). Conscious sedation with neuroleptic analgesia (morphine 10 mg) permits continuous feedback from the patient during the entire procedure. Once anesthesia is assessed by checking the sensory level, the surgery commences. Intraoperatively, the patient's sensory and motor changes can be detected because this type of anesthetic procedure does not block the nerve root completely.

The sequence of surgery is identical to the general percutaneous TfELD procedure. What distinguishes the surgical technique in this study from that employed in standard PELD is the use of the facet process and pedicle complex as the approach target for docking of the guide needle. Preoperative imaging studies, in addition to intraoperative fluoroscopy, are conducted to ascertain the entry site. The skin entry point is typically 8–12 cm from the midline. The exact distance from the midline depends on the patient's anatomy. A greater distance from the midline is preferable if the patient is obese or has a wide lower back. The oblique caudal directional line is drawn from the superolateral to the inferomedial margin of the ipsilateral pedicle on the X-ray orthogonal anteroposterior view. The target of the spinal needle is the medial pedicular margin on the anteroposterior image and the posterior vertebral line on the lateral image. The approach angle on the X-ray anteroposterior view should be adjusted according to the target area, i.e., a more caudal angle in inferiorly migrated cases and a less caudal angle in superiorly migrated cases.

After local anesthesia is achieved around the skin entry point, an 18-gauge spinal needle is introduced under fluoroscopic guidance, and the subcutaneous tissue, muscle layers, facet joint, intervertebral foramen, and epidural space along the trajectory are infiltrated with local anesthetic. The spinal needle is then replaced with a guidewire. A 1-cm stab wound is made in the skin, and the thinnest guide rod is slid over the guidewire and docked firmly in the ideal position on the posterolateral side of the junction of the superior articular process (SAP) and transverse process. Subsequently, three more dilators of increasing diameter are advanced over the cannulated guide rod to widen the soft-tissue channel. An 8.5-mm-diameter trephine protection tube is slid over the dilator, and the dilators are then removed. The guidewire is then replaced with a 2.0-mm-diameter Kirschner wire (K-wire) by tapping carefully with a hammer under fluoroscopic guidance. For the anatomic differences and to avoid dura or nerve injury, the tip of the K-wire is positioned at the pedicular medial margin in the anteroposterior projection and at the posterior vertebral line in the lateral projection

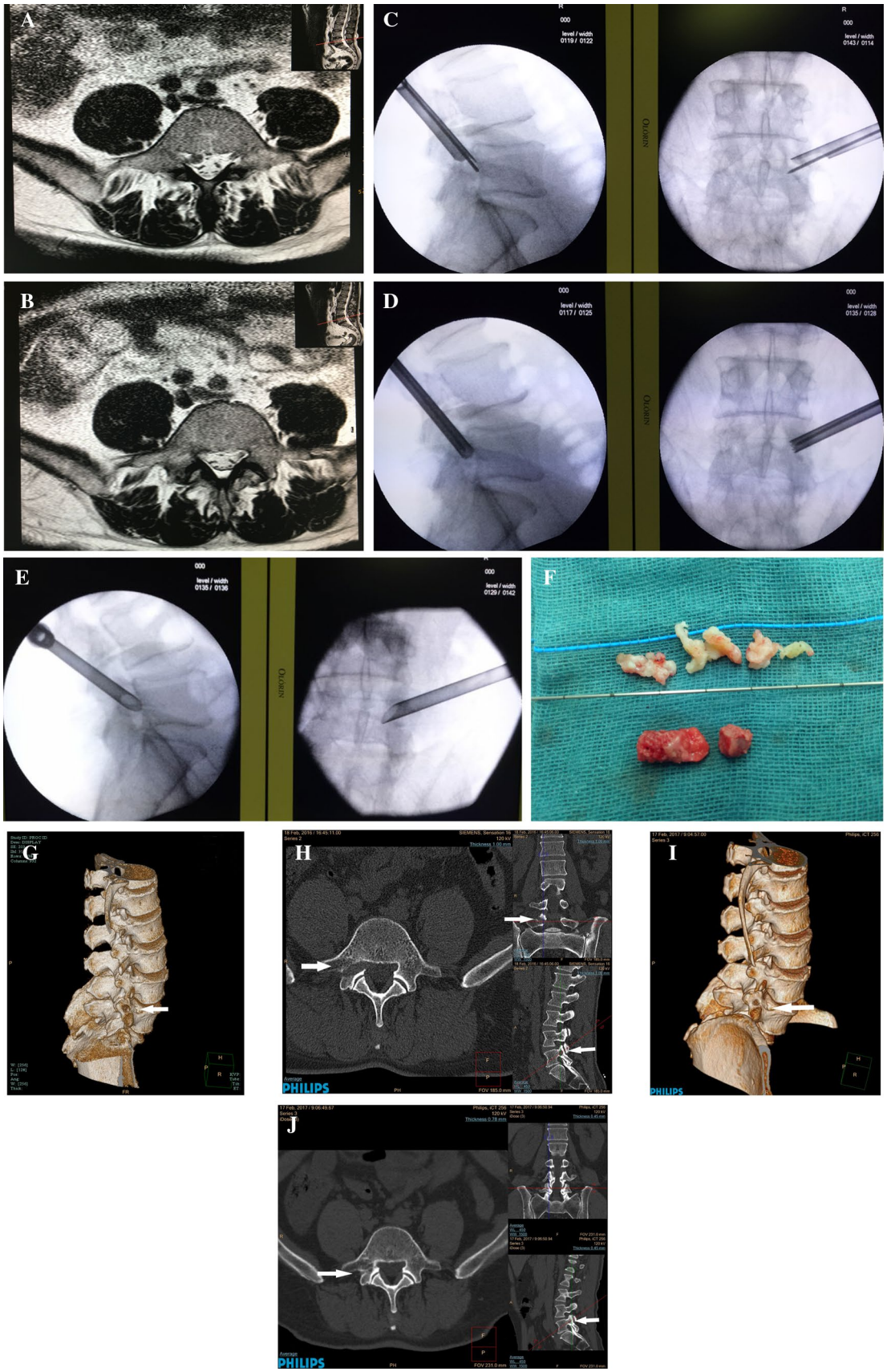
just before penetrating the spinal canal. A 7.6-mm diameter trephine is inserted into the epidural space in an inferomedial direction toward the herniated disc and maneuvered through facet process and pedicle bone complex by rotating it slowly with moderate pressure. There is a loosening sensation when the trephine advances beyond the medial margin of the pedicle. The trephining procedure is controlled radiologically in two planes. After removing the trephine along with bone and K-wire, the last guide rod is inserted along the bone tunnel and the trephine protection tube removed. The 7.5-mm-diameter working cannula (SPINENDOS GmbH, Munich, Germany) is then advanced over the last guide rod into the spinal canal and the guide rod removed. Fluoroscopic imaging is used to check the precise position of the working cannula in two planes. The trephining procedure is simple and quick (5–10 min). A 6.3-mm OD spinal endoscope with a working channel of 3.75 mm (SPINENDOS GmbH) is then inserted into the round end of the working cannula. The endoscope with cannula is gradually rotated in the superior, inferior, or dorsal direction depending on the position of the sequestered nucleus pulposus. The herniated nucleus pulposus located in the anterolateral aspect of the exiting root is easily recognized. The sequestered fragment is released with a flexible bipolar radiofrequency probe (Trigger-Flex® Bipolar System, Elliquence LLC, Baldwin, NY, USA) and manually removed with endoscopic forceps under direct vision (Fig. 4a, b). Bleeding can be controlled with the Trigger-Flex® device (Elliquence). After complete decompression, the exiting nerve root should move freely with the Valsalva maneuver.

In the present cases, 2 days after the operation, the patients were ambulatory and pain-free, and successful decompression of the traversing nerve root was confirmed on postoperative MRI.

Discussion

Since the late 1990s, PELD has been regarded as a practical alternative to conventional open discectomy in the treatment of lumbar disc herniation [6]. The PELD technique has greatly improved over the past 10 years, and there have been many reports on the merits of PELD, such as less tissue trauma, shorter hospital stays, earlier return to normal activity, fewer complications and morbidities in the elderly and, thus, greater patient satisfaction [10–12]. With experience and advances in surgical instruments, some past contraindications are now indications [13–16].

Lee et al. [17] and Choi et al. [18] defined high-grade disc migration as migration greater than the measured height of the posterior marginal disc space. Kim et al. [19] described very high-grade disc herniation migration as that extending beyond the inferior margin of the pedicle in either the upward or downward direction. However, the use PELD for high-grade migrated disc herniation is technically demanding and can result in less favorable outcomes [17, 20]. Lee et al. [17] reported that patients with high-grade migrated discs have less favorable outcomes than those with near-migrated or non-migrated discs treated with conventional transforaminal PELD. However, there is no consensus as to the degree of migration that can be removed using current endoscopic instruments through the standard approach. The osseous perimeter of the foramen, the facet process, the pedicle, and the exiting nerve can limit proper trajectory of insertion, and the mobility, of the working cannula as well as excision of dislocated or migrated herniated material. It is therefore challenging to treat high-grade migrated-disc herniation with conventional transforaminal PELD. The success of the PELD procedure depends on the appropriate placement of the working instruments. Improper trajectory to the pathology is a major cause of the failure of this procedure. Ruetten et al. [6] reported that it was difficult to remove the disc fragments, even if an extreme lateral approach was applied, in the trans-ligamentous or completely sequestered types, with inferior migration lower than the middle pedicle of the lower vertebra. This limitation is because the result of the lack of flexibility of the endoscope and instruments inserted through the working channel of the endoscope, so treating very high-grade migrated disc that is beyond the inferior margin of pedicle level with PELD would require revolutionary development in surgical instruments and/or advanced endoscopic approach technique. Nucleus pulposus surgery at the L5–S1 segment can be performed without removal of surrounding bone because the interlaminar space in this segment is very large. In most Asians, the interlaminar spaces at the L4–5 and higher segments are very small, so some laminar bone tissue should be removed. An intralaminar working channel that is poorly or laterally established may cause injury to the vertebral isthmus. The pars interarticularis is one of the most fragile parts of the lumbar spine [21], and Ivanov et al. [22] demonstrated that the risk of stress fracture increases significantly when removing its lateral half. Preserving the continuity of the pars interarticularis is particularly important in patients with recurrent surgery who have previously lost considerable bone; for example, because extensive laminotomy [23]. If endoscopic discectomy is performed via an interlaminar approach, and the bone tunnel should be expanded using a high-speed endoscopic drill system. In most hospitals in China, the endoscopic drill system is not available. PELD using a posterolateral approach is widely used and is suitable for discectomy in most lumbar segments. Some laminar bone can be removed using a bone drill or trephine, and a working channel can be established using a conventional tool. Based on the idea of using a cervical anterior approach to remove a completely inferiorly migrated nucleus pulposus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◂**Fig. 2** T2-weighed magnetic resonance (MR) images in the axial plane along with topogram of the same patient showing downward migration of the herniated disc compressing the right L5 nerve root preoperatively (**a**) and removal of the down-migrated disc fragment postoperatively (**b**). Fluoroscopic images showing the position of the tip of K-wire anchored in the facet process and pedicle complex in the lateral view and slight downward inclination of the K-wire from the superolateral to the inferomedial margin of the ipsilateral pedicle on anterolateral view (**c**). The trephine is advanced slowly over the K-wire in an inferomedial direction toward the herniated disc (**d**). Fluoroscopic images showing position of the working cannula and slight downward inclination from the superolateral to the inferomedial margin of the ipsilateral pedicle on anterolateral view, with the tip of the working cannula located at the posterior vertebral line in the lateral projection (**e**). Material from the migrated disc material was removed in three pieces and circular bone was trephined (**f**). Postoperative 3D CT image shows the tunnel (white arrow) made through the L5 right facet process and pedicle complex (**g**). Postoperative CT image in axial view, sagittal and coronal views show the tunnel (white arrow) (**h**). Twelve-month 3D CT image shows healing of the bone tunnels in the L5 right facet process and pedicle complex (white arrow) (**i**). Twelve-month-postoperative CT image in axial view, sagittal and coronal views show the healing of the bone tunnel (white arrow) (**j**). 3D CT three-dimensional computed tomography

through the vertebral bone channel, we felt that removal of a completely inferiorly migrated nucleus pulposus could be achieved through the established channel using a percutaneous posterolateral approach. Our new approach, which is performed the PELD via a facet process and pedicle-complex approach is an alternative to direct herniectomy for a distally completely inferiorly migrated nucleus pulposus, and the results are comparable to those obtained with conventional transforaminal PELD to treat non-migrated discs. The completely inferiorly migrated nucleus pulposus can be removed conventionally through the intervertebral foramen. Nucleus pulposus remaining in the spinal canal at the pedicle level can be removed through PELD via a facet process and pedicle-complex approach. Unlike a procedure involving an interlaminar approach, which requires general or epidural anesthesia for a safety, our entire procedure can be performed under local anesthesia with conscious sedation. And surgery under general anesthesia costs more than surgery under local anesthesia. Chinese patients would prefer to receive PELD surgery under local anesthesia using a posterolateral approach, which exhibits curative effects similar to those of endoscopic discectomy via an interlaminar approach under general anesthesia. The bone cannula made from the trans-facet pedicle does not pass the lumbar spinal facet joint, does not cause iatrogenic injury to the facet joint, and heals like any bone fracture. PELD via a facet process and pedicle-complex approach destroys only part of bone structure in the posteromedial part of the pedicle, it does not destroy the lateral, superior, and inferior walls of the pedicle. To reduce the destruction of the facet process and the posterior part of the pedicle, the channel opening can be directed slightly upward. In the present study, a spinal needle was used to orient the position of the protruding nucleus pulposus. A working channel was established along the spinal needle using a trephine. Multiple orientations are not allowed. The trephining procedure is controlled radiologically in two planes (anteroposterior and lateral). Under endoscopy, a prominent nucleus pulposus can be directly visualized and removed. In the present study, no pedicle fracture was incurred during surgery by any of the patients. Postoperative MRI revealed that migrated nucleus pulposus was completely removed. CT scans showed no destruction or expansion of the completely migrated nucleus pulposus by the facet process and pedicle-complex channel. Follow-up examination showed healing of the bone channel.

In the PELD via a facet process and pedicle-complex approach, accurate placement of the trans-facet process and pedicle-complex tunnel is considered as the first and most important step. During preparation of the facet process and pedicle-complex bone tunnel, damage to the SAP and pedicle are anticipated and affect the biomechanical strength of the lumbar spine facet joint. Robertson et al. [24] determined the width and height of the L1 through L5 pedicle in the coaxial plane to be 9.5–21 and 17.6–19.9 mm, respectively. Kadioglu et al. [25] reported that lumbar pedicle width and pedicle height of Eastern populations were 8.8–14.6 and 13.4–14.7 mm, respectively, on CT studies and 6.4–12.4 and 13.0–14.2 mm, respectively, by dried specimen anatomic measurement. Lien et al. [26] analyzed the morphometric characteristics of Taiwa populations lumbar spine pedicles and concluded that the ranges of the safe-zone width and height were 8.2–17.8 and 13.9–16.7 mm, respectively, in L1 through L5. The lateral distance between nerve root and the pedicle ranged from 2.4 to 9.6 mm in the lumbar spine. This study provides potential safe zones for the application of the PELD via a facet process and pedicle-complex access procedures to help decrease the risk of intraoperative complications.

There is evidence that both conventional open intervertebral disc removal and minimally invasive endoscopic discectomy have the potential to lead to recurrent lumbar disc herniation or lumbar disc degeneration, both of which require secondary surgery [8] or fusion. During PELD via a facet process and pedicle-complex, access is selected at the posterolateral position of the base of the superior articular process above the transverse process. The tunnel was tangential to the posteromedial part of the pedicle and caused less damage to the weightbearing structure of the pedicle. The opening does not influence the entry point for conventional pedicle screw implantation, i.e., the intersection point between the median line of the transverse process and the exterior margin of the articular process. Thus, a pedicle screw can be properly inserted. To avoid deviation of the orientation of pedicle screw along the facet process and pedicle-complex

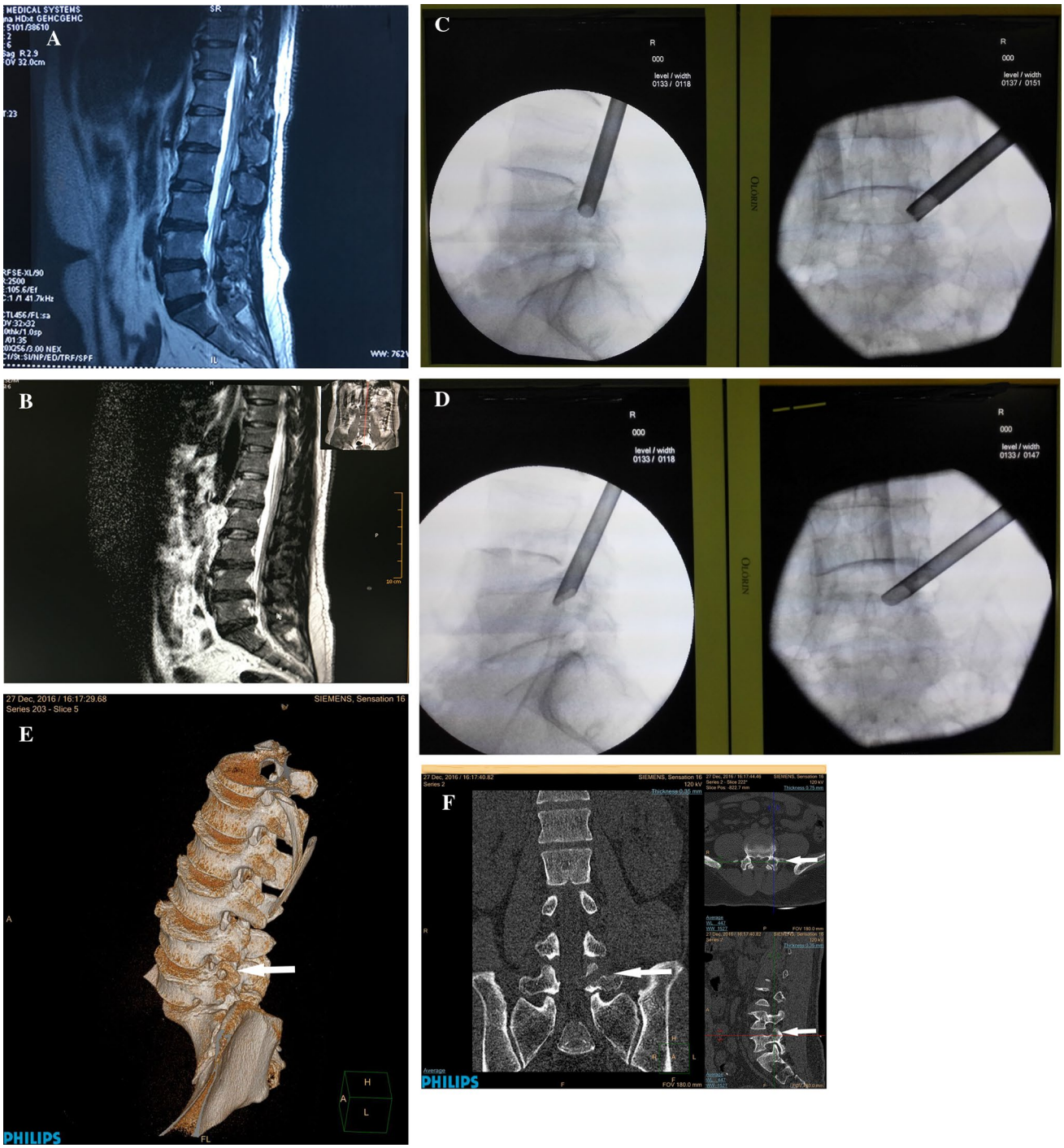

Fig. 3 Preoperative T2-weighed MR images in the sagittal view of the same patient show a downward migration of the herniated disc compressing the left L5 nerve root (**a**). Postoperative T2-weighed MR images in the sagittal plane along with topogram show that the down-migrated disc fragment has been removed (**b**). Fluoroscopic images showing the trephine is advanced slowly over the K-wire from the superolateral to the inferomedial margin of the ipsilateral pedicle on anterolateral view toward the target (**c**). Fluoroscopic images showing position of the working cannula and slight downward inclination from the superolateral to the inferomedial margin of the ipsilateral pedicle on anterolateral view, the tip of working cannula located at the posterior vertebral line in the lateral projection (**d**). Postoperative 3D CT image shows the tunnel (white arrow) made through the L5 left facet process and pedicle complex (**e**). Postoperative CT image in the axial, sagittal, and coronal views shows the tunnel (white arrow) (**f**). 3D CT three-dimensional computed tomography

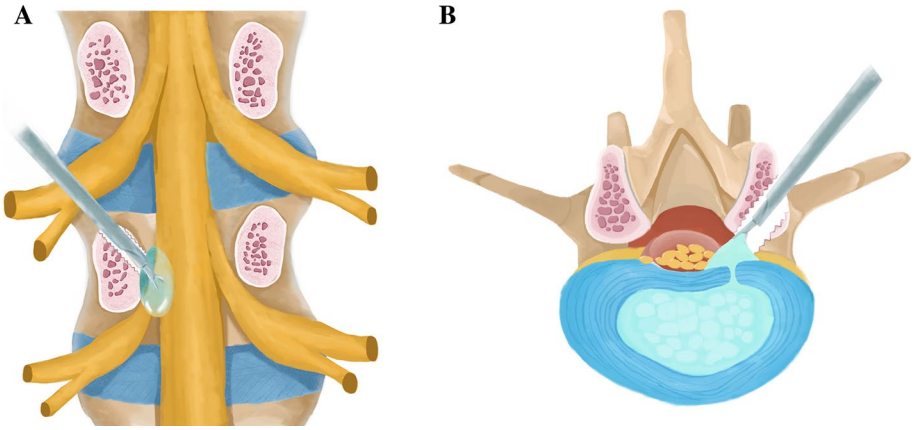

Fig. 4 **a**, **b** Schematic drawings of removal of high-grade down-migrated sequestered fragment via a trans-facet–pedicle approach using the percutaneous endoscopic lumbar discectomy technique

access, the abduction angle of the pedicle screw can be slightly increased. If interbody fusion is required in the early stage of spinal revision surgery, if pedicle implantation fails, a normal unilateral pedicle screw, cortical bone trajectory screw [27], or articular screw [28] can be used.

In the present cases, the following were potential complications of The PELD via a facet process and pedicle-complex approach. First, there was a risk of fracture of the SAP and pedicle. This can be prevented by using the proper rotational direction and not using an oversized trephine. The bone tunnel was created with a 7.6-mm-diameter trephine and the direction of the trans-facet–pedicle-complex tunnel was from the superolateral to the inferomedial margin of ipsilateral pedicle on the X-ray orthogonal anteroposterior view and from the posterolateral to the anteromedial margin of the pedicle in axial view. No fracture of the pedicle or facet was observed during the follow-up period. CT obtained 10 months postoperatively revealed partial or complete healing of the bone tunnel of the facet process and pedicle complex. Second, injury to the nerve root and dural sac was possible. Rotation of the trephine was slow, with moderate pressure, and the precise position of the trephine was checked in two planes on imaging. During this process, the surgeon often tested for sensory and motor changes in the patient.

In conclusion, PELD via a facet process and pedicle-complex approach can be considered an alternative treatment in lumbar disc herniation with high-grade down-migrated disc.

Compliance with ethical standards

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

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