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ORIGINAL ARTICLE

Multilevel mini-open TLIFs and percutaneous pedicle screw fixation: description of a simple technical *nuance* used to increase intraoperative safety and improve workflow. Tips and tricks and review of the literature

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Abstract We describe a technical variation used to enhance intraoperative safety and efficiency in multilevel percutaneous pedicle screw fixation (PPSFs) and mini-open transforaminal lumbar interbody fusion (m-TLIFs). A review of the literature on percutaneous screw insertion techniques and related pitfalls is presented. PPSFs and m-TLIFs are increasingly used techniques in multilevel lumbar degenerative disease. Facetectomy and TLIF are usually performed before inserting ipsilateral pedicle screws. Such techniques can cause unintended violation of the pedicle and injure the dura or neural structures, particularly in multilevel cases. A literature review revealed a lack of intraoperative and fluoroscopic images detailing the technique for multilevel PPSF and m-TLIF(s) performed through tubular, expandable retractors. Thirteen patients with two- to four-level disease underwent multilevel PPSF and m-TLIF (one to four levels). The Kirschner Cage Screw (KCS) technique, consisting of early insertion of K-wires in all pedicles followed by facetectomy and m-TLIF(s) and, finally, screw insertion, was used in order to minimize the risk of dural/neural injuries. Neither CSF (cerebrospinal fluid) leaks nor nerve root injuries nor technique-related complications were encountered with a follow-up ranging from 7 to 38 months (mean 23.6). In conclusion, the KCS technique allows safe identification of the pedicles without opening the canal during m–TLIF(s). Moreover, by visualizing the K-wires inside the retractor, the surgeon can check the pedicle position during facetectomy, and screws can be introduced with a minimal risk of neural or dural injuries. We believe that the proposed technique increases the safety and ease of the procedure, particularly in multilevel cases.

Keywords Cage · Kirschner wire · Lumbar spine · Minimally invasive surgery · Percutaneous screw fixation · TLIF

Introduction

During the recent past, a rising concern regarding postoperative morbidity associated with open lumbar spine fixations (e.g., paraspinal muscle denervation and atrophy contributing to postoperative back pain and impaired function) prompted the rapid evolution of minimally invasive techniques [2, 5, 11, 12, 19, 32, 42, 49].

In 2003, Foley et al. described a minimally invasive TLIF (MI-TLIF) technique using percutaneous pedicle screw fixation (PPSF) performed through a fixed tubular muscle dilator [9, 10]. Since then, the MI-TLIF has been increasingly used to treat symptomatic patients, including elderly ones [23], suffering from lumbar degenerative conditions. Several authors have reported their experience using fixed tubular retractors [3, 7, 8, 14, 16, 20, 21, 23, 30, 31, 33, 43–45, 47] or expandable ones [14, 18, 25, 52]. The latter have the advantage of providing a wide surgical field but is also associated with exposure of more anatomical structures and a consequent increased risk of loss of orientation and inadvertent damage of either bony or neural structures. In such a situation, the surgeon is often induced to repeatedly use fluoroscopy to check the correct position before either starting to remove

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the soft tissues over the facet joint or to insert the pedicle screws.

A literature review of published studies highlighted a lack of intraoperative and fluoroscopic images describing the technical pitfalls and tips during multilevel MI-TLIFs and PPSF through expandable retractors.

In these cases, which are currently less common but likely to become more numerous in the future due to the growing use of minimally invasive spine surgery, the same skin incision allows both the insertion of two or three screws and the MI-TLIF. It is therefore important to use an effective and safe surgical technique.

Percutaneous pedicle screw fixation and MI-TLIF is a technically challenging surgery [22, 33], requiring a thorough understanding of the three-dimensional anatomy as perceived through tubular retractors, particularly during the initial learning phase. Kang and Frempong highlighted the importance of studies focusing on multilevel percutaneous MI procedures [43]. The current paper's goal is to report our experience and technique for multilevel MI-TLIFs and percutaneous pedicle screw fixation technique.

Patients and methods

Thirteen patients (nine females), aged 50 to 79 (mean age 66.8) years, were diagnosed with multilevel degenerative disc disease (DDD) causing low-back pain, neurogenic intermittent claudication (NIC), and/or radiculopathy.

Conservative treatment had failed in all cases. Seven patients presented with a Meyerding grade 1 or 2 degenerative spondylolisthesis. A concomitant lumbar central canal stenosis was present in all cases. Eight patients underwent a two-level percutaneous pedicle screw fixation (screws in three vertebral bodies) and mini-open TLIF (m-TLIF). Three patients had a three-level procedure and two patients had a four-level surgery, from L2 to S1. m-TLIF was performed at one, two, or four intervertebral levels. In total, 86 screws and 19 interbody cages were inserted (Table 1).

Interbody cages were filled with local autologous bone and/or silicate substituted calcium phosphate (Actifuse; Baxter).

VAS (Visual Analogue Scale) and ODI (Oswestry Disability Index) were used to evaluate patients before and after surgery. X-rays, with flexion–extension views, multiplanar computed tomography (CT), and magnetic resonance imaging (MRI) of the lumbar spine were obtained before surgery. X-rays and CT scans were used postoperatively. Follow-up ranged from 7 to 38 months (mean 23.6 months).

All patients were operated on using a technical variant, named Kirschner Cage Screw (KCS) technique, described below. This is based on early introduction of Kirschner wires (K-wires) in all pedicles before drilling away the facet joint(s) and ipsilateral lamina to perform the m-TLIF and decompressing the neural structures.

The described multilevel cases were not part of our learning curve; we previously used the same KCS technique in single-level cases.

An expandable tubular retractor, which in our experience provides both a satisfactory working space and an excellent view under the microscope, was used in all cases to perform the microsurgical decompression of neural structures and the MI-TLIFs. Moreover, the correct placement of the retractor allows simultaneous exposure of the facet joint to be removed, the underlying disc space, part of the adjacent cranial, the caudal laminae, and the central canal area. The inferior edge of the cranial pedicle and the superior edge of the caudal one are also in the field. In selected cases, two expandable tubular retractors placed on either side are used to perform bilateral decompression, with/without m-TLIF(s), at the same spine level or at different levels.

Surgical technique for multilevel, percutaneous pedicle screw fixation and mini-open TLIF(s)

Under general anesthesia, the patient is positioned prone, maintaining the physiological lumbar lordosis, on a radiolucent table (Magnus; Maquet) supplemented with a specifically designed carbon-fiber extension for spine surgery. This also allows the use of an imaging intensifier (Arcadis, Orbic 3D; Siemens), which can rotate from antero-posterior (AP) to lateral position without impinging against the base of the table.

After positioning the patient, an AP fluoroscopic image is obtained, making sure that the spinous process of the first index vertebra is centered in the midline, between the two pedicles, and the superior vertebral endplate of the vertebra appears straight and as a single line.

We prefer to start the surgical procedure on the contralateral side of the planned TLIF. Under AP fluoroscopic control, a thin metallic instrument, like a K-wire, is placed in line with the outer border of the ipsilateral pedicles. The skin is marked and incised about 2 cm lateral to the bar; this allows a lateral to medial trajectory of the percutaneous instruments, and finally of the screws, using a Wiltse-type approach. Such a technique allows for better triangulation of the screws, with their tips aiming towards the midline of the inner vertebral body, so increasing the resistance to pull-out.

Usually, multiple skin incisions are performed to insert the percutaneous screws; at the L5-S1 level, a single skin incision is used when the distance between the two screws is small. A Jamshidi needle, followed by a K-wire, is inserted into the pedicles and, after checking the trajectory with lateral fluoroscopy, the cannulated screws are inserted over the K-wires using the standard technique [28]. On the other side, after identifying the pedicles as described above, a single skin

Table 1 Summary of multilevel pedicle-screw fixation procedures and MIS-TLIFs

Patient no.	Age (years)/sex	Clinical presentation	Pathology	Treated levels	Level/side of TLIF	Complications D/N
1	71/M	NIC, radiculopathy	LSCS, FS, facet arthropathy, SL	L2–L3–L4	L3–L4/L	None
2	77/F	Radiculopathy	FS, facet arthropathy	L2–L3–L4–L5	L4–L5/L	None
3	77/F	NIC, radiculopathy	LSCS, facet arthropathy	L2–L3–L4–L5	L4–L5/R	None
4	66/F	NIC, radiculopathy	LSCS, FS, SL	L4–L5–S1	L5–S1/L	None
5	64/F	NIC, radiculopathy	LSCS, FS, facet arthropathy	L4–L5–S1	L5–S1/R	None
6	50/F	NIC, radiculopathy	LSCS, facet arthropathy, SL	L3–L4–L5	L4–L5/R	
7	64/M	Radiculopathy	FS, facet arthropathy	L3–L4–L5–S1	L3–L4/L, L4–L5/L	None
8	71/F	Radiculopathy	FS, facet arthropathy, SL	L4–L5–S1	L4–L5/L	None
9	61/M	Radiculopathy	LSCS, FS, facet arthropathy	L2–L3–L4–L5–S1	L2–L3/R, L3–L4/L, L4–L5/R, L5–S1/L	None
10	66/F	NIC, radiculopathy	LSCS, FS, SL	L3–L4–L5	L4–L5/R	None
11	72/F	NIC, radiculopathy	LSCS, FS, SL	L3–L4–L5	L4–L5/L	None
12	52/M	NIC, radiculopathy	LSCS, FS	L2–L3–L4–L5–S1	L3–L4/L, L4–L5/R, L5–S1/L	None
13	79/F	NIC, radiculopathy	LSCS, FS, SL	L3–L4–L5	L4–L5/L	None

NIC neurogenic intermittent claudication, *LSCS* lumbar spine canal stenosis, *FS* foraminal stenosis, *SL* spondylolisthesis, *D* dural, *N* neural

incision linking together the pedicles above and below the planned disc level for the TLIF(s) is performed (Fig. 1). The m-TLIF is usually performed on the side with worse radicular symptoms or, in cases with bilateral symptoms, on the side where the compressive disease is worse on imaging.

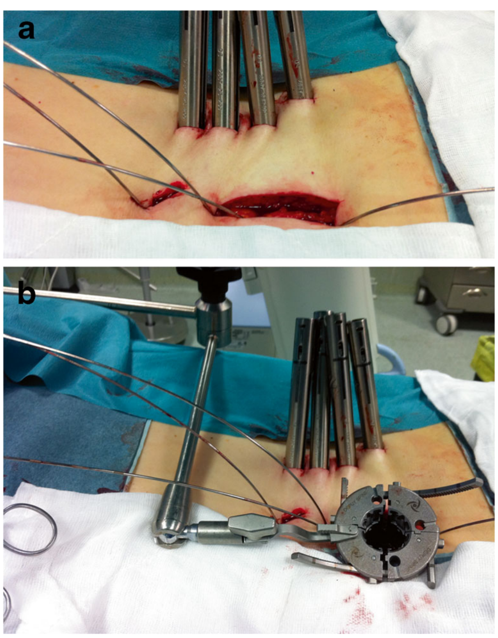

Fig. 1 Intraoperative picture showing the inserted screw extensions on one side (**a**) and all K-wires with the expandable tubular retractor on the other side, where the decompression and m-TLIFs will be performed (**b**) during a multilevel surgery. One should note the shorter cranial incision for one pedicle screw and a caudal, longer one used both to insert three pedicle screws and two adjacent m-TLIFs (**a**). The tubular, expandable retractor has been introduced and the K-wires are positioned at either side (**b**)

In multilevel cases, when two adjacent TLIFs are scheduled, a single skin and fascia incision including all three pedicles and the two intervening disc spaces is made; the other pedicle screws are inserted through additional, smaller skin incisions. A Jamshidi needle is then inserted into the first pedicle, and through it a K-wire is passed and left in place. The wire is bent down and secured with a towel clip. The same technique is applied to the other pedicles before carrying out the facetectomy and the m-TLIF. Therefore, all pedicles are identified and K-wires are left inside each vertebral body before introducing the tubular, expandable retractor and drilling out any bone (Fig. 1). Under AP fluoroscopy, sequential dilator tubes are inserted to progressively and bluntly split the paraspinal muscles over the index facet joint, and an expandable tubular retractor, held in place by an articulated-arm clamp, is then docked over it (Fig. 2).

In multilevel cases, according to the extent of decompression to be performed (i.e., unilateral vs. bilateral facetectomy and m-TLIFs), two technical options can be used. One can insert pedicle screws on one side and intrapedicular K-wires on the other side (in case of unilateral decompression and m-TLIF). Alternatively, one can place intrapedicular K-wires bilaterally (in patients requiring bilateral decompression and m-TLIFs at every other intervertebral space) (Fig. 3). The microscope is brought in at this time. If required for further safety, particularly during the initial learning curve, after stripping the muscles off the facet joint, and slightly angulating the microscope, it is possible to see the K-wires entering the cranial and caudal pedicles on the inner surface of the retractor's blades (Fig. 4). It is important to note that the presence of the K-wires does not pose any problems for placing the expandable retractor nor, in our experience, is there a risk of

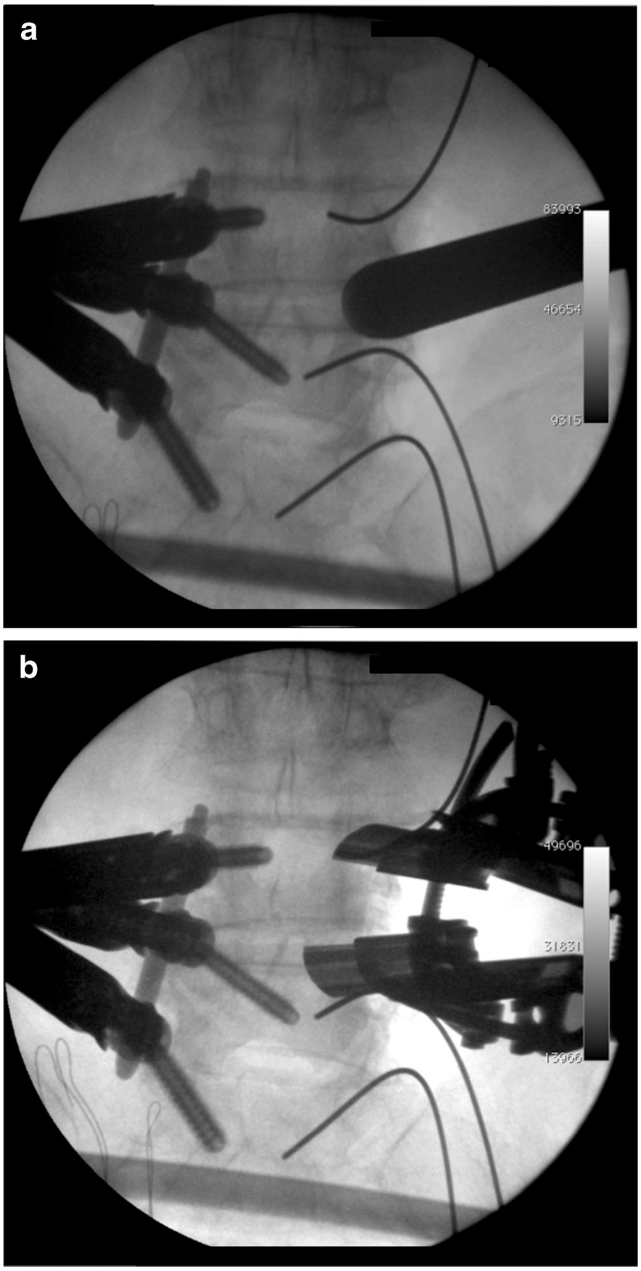

Fig. 2 Fluoroscopic AP image showing percutaneous pedicle screws and rod inserted on one side before performing the m-TLIF contralaterally; K-wires are inserted in all contralateral pedicles (**a**). The tubular, expandable dilator is positioned over the facet, between the K-wires. Two K-wires are seen within the retractor's blades (**b**)

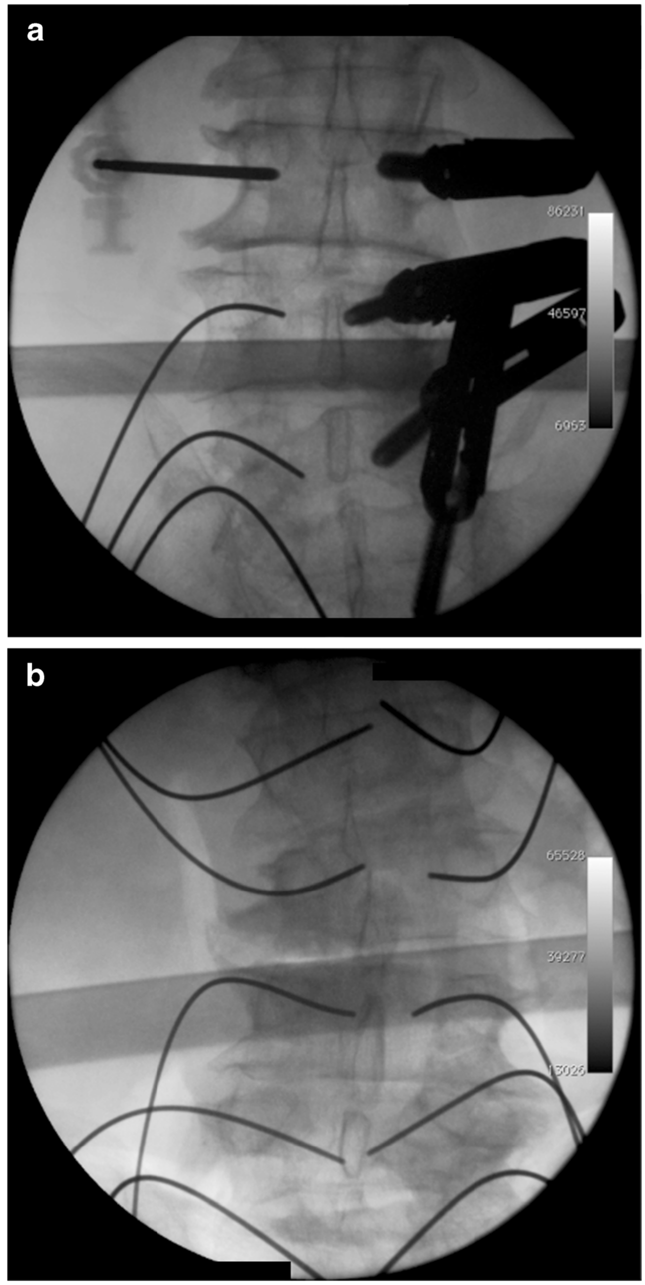

Fig. 3 Fluoroscopic AP image showing the two options used in multi-level cases: percutaneous pedicle screws inserted on one side and K-wires in all contralateral pedicles (**a**); only K-wires are inserted in all pedicles, bilaterally, before performing any facetectomy (**b**)

wire breakage by the expanded retractor. If a central canal decompression is needed, the retractor can be directed more medially, towards the base of the spinous process. A more medial orientation also allows a contralateral nerve root decompression through a single-side minimally invasive surgery (MIS) approach (Fig. 5). In cases of adjacent TLIFs, the expandable retractor is repositioned between the other two K-wires, on the other facet joint, always through the same skin and fascia incision. Using the standard technique, a high-speed drill and/or Kerrison roungers are used to perform the facetectomy, and a single, bullet-shaped carbon fiber reinforced polymer (CFRP) or polyetheretherketone (PEEK) cage packed with autologous or silicate substituted calcium phosphate (Actifuse ABX; Baxter) bone graft is inserted. If necessary, the contralateral screws and rod can be used to apply some intervertebral distraction and facilitate both the access to and the maneuvers within the disc space and the cage insertion. Nonetheless, careful use of spreaders and shavers within

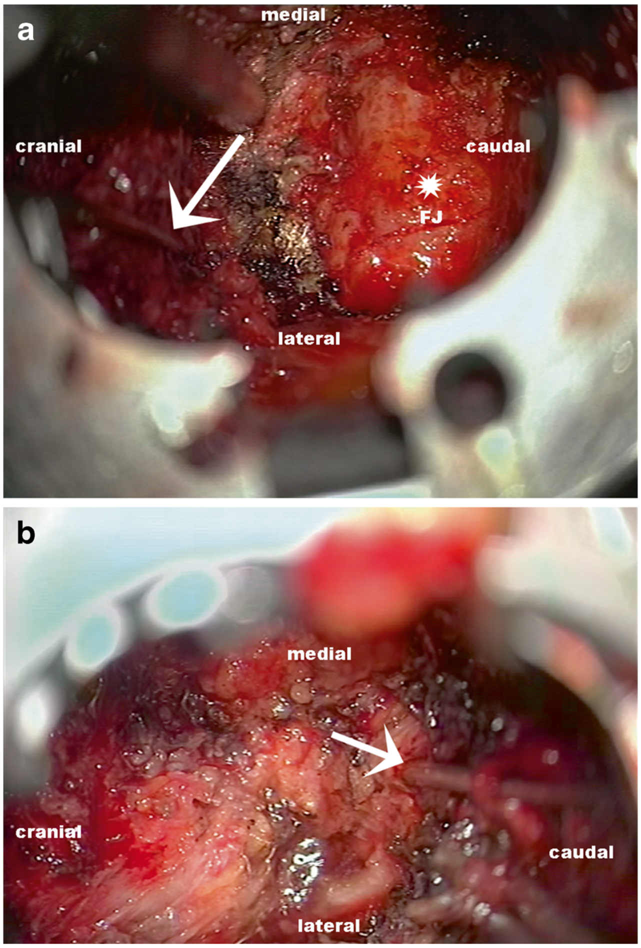

Fig. 4 The tubular, expandable retractor has been inserted from the patient's left side. Microscopic picture through the expandable retractor showing the facet joint (*white asterisk*) and the K-wire entering the cranial pedicle (*arrow*) (**a**). The second K-wire (*arrow*) placed into the caudal pedicle is visualized inside the retractor before starting the drilling of the facet joint (**b**)

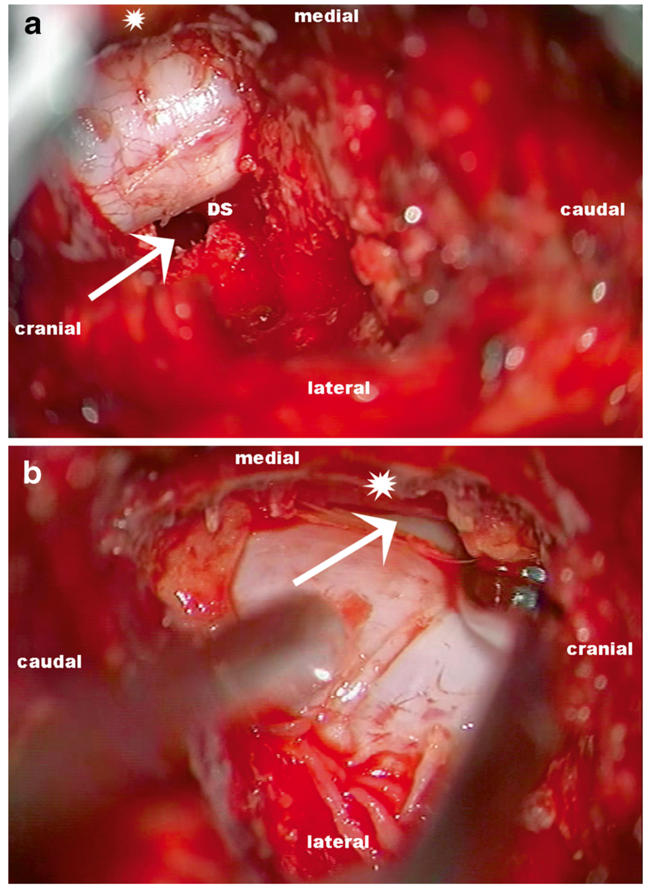

Fig. 5 Intraoperative, microscopic images seen through the expanded tubular retractor showing a thoroughly decompressed thecal sac and prepared disc space (DS) for the m-TLIF, following facetectomy and hemilaminectomy. *Asterisk* indicates contralateral side of the canal and *arrow* the disc space (**a**). Another case: the base of the spinous process and the interspinous ligament (*asterisk*) has been trimmed and, after slightly tilting the table, the contralateral side of the canal and nerve root can be visualized (*arrow*) (**b**)

the disc space allows, in most cases, a satisfactory disc space height restoration. The retractor is then removed and the percutaneous screws are inserted at all levels, under only minimal lateral fluoroscopic control, using the K-wires previously positioned inside the pedicles. The procedure is completed by inserting the rods and applying compression to the cage(s).

Illustrative cases

Case 1

An otherwise healthy 64-year-old man was referred because of a long-standing history of low-back pain associated with left-sided sciatica, paresthesiae, and NIC unresponsive to conservative treatment. Other than having reduced light-touch and pinprick sensation in the left L4 dermatome and decreased left knee reflex, the neurologic examination was otherwise unremarkable. Preoperative lumbar spine x-rays, with flexion/extension views, did not show any overt instability. CT and MRI scans revealed a multilevel lateral canal stenosis (i.e., from L3 to S1), with disc herniation and spondylotic changes at L3–L4 and L4–L5 disc levels causing foraminal stenosis, mostly on the left side (Fig. 6). After obtaining an informed consent, a left-sided laminectomy and facetectomy at L3–L4 and L4–L5 levels, followed by microsurgical neural decompression, were performed through an expandable tubular retractor (Pipeline, DePuy Spine; Johnson&Johnson). At the same levels, m-TLIFs were carried out using a single, bullet-shaped CFRP cage per level (Concorde, DePuy Spine; Johnson&Johnson) packed with autologous bone chips.

Pedicle screws from L3 to S1 (Viper2, DePuy Spine; Johnson&Johnson) were inserted percutaneously. The right

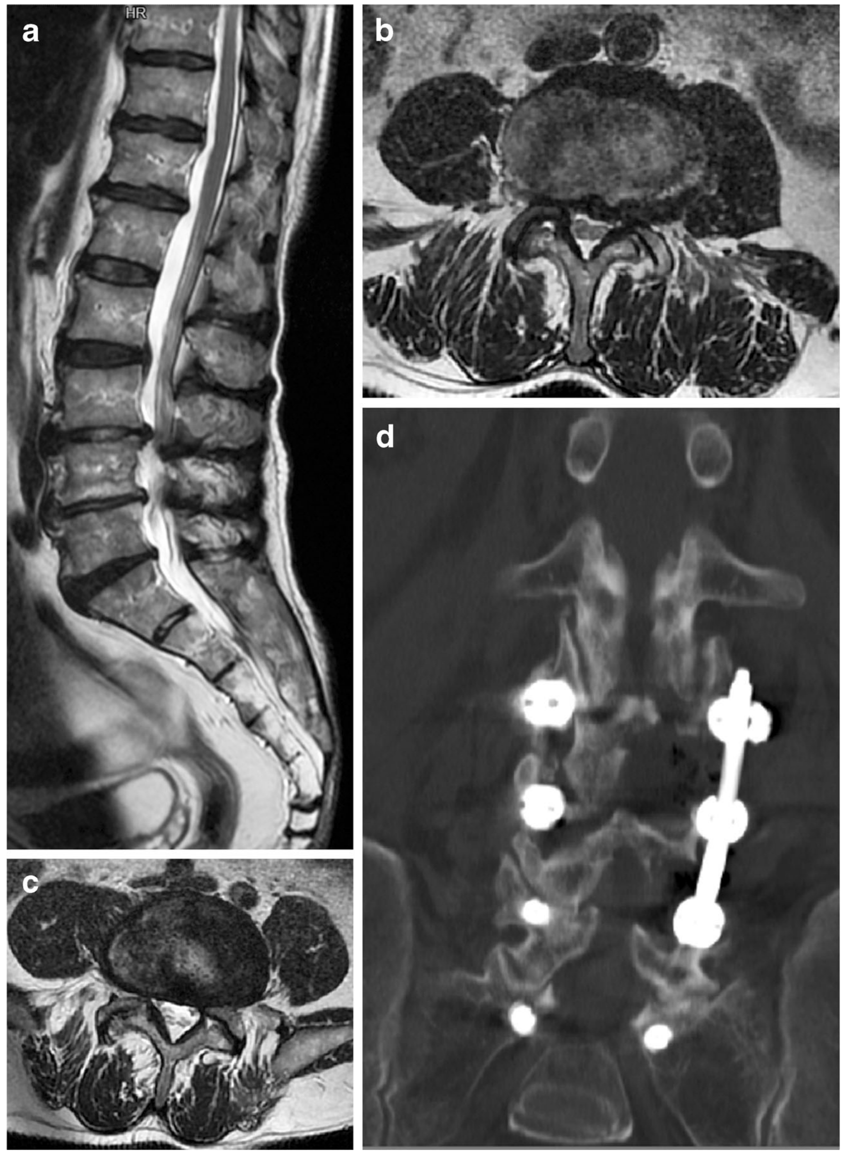

Fig. 6 Sagittal, T2-weighted lumbar MRI demonstrating multilevel canal stenosis (**a**); axial, T2-weighted MRI at L3–L4 (**b**) and L4–L5 (**c**), respectively, confirming the canal (foraminal) stenosis worse on the left side. Coronal CT scan reconstruction highlighting the right-sided facetectomies and hemilaminectomies at L3–L4 and L4–L5 (**d**)

L3 screw required cement augmentation, which was performed using a cannulated and fenestrated screw. The surgical technique is described in detail in the paragraph above.

Postoperative x-rays, CT, and MR imaging confirmed the decompression of the neural structures and correct position of all instrumentation (Fig. 6). Follow-up at 27 months confirms clinical improvement, with ODI improvement from 60 to 35 % and a VAS improvement from seven (preoperatively) to two.

Case 2

A 61-year-old man presented with a several-month history of low-back pain radiating down both lower limbs and NIC. Urinary urgency was present in the last month as well as progressively increasing difficulty with ambulation. Ten years earlier, he had already undergone a left-sided L5 laminectomy and, 1 year later, a right-sided L3–L4 laminectomy for compressive radiculopathies secondary to degenerative disc disease. Because of recurrent symptoms, unresponsive to conservative treatment, he was worked up with MRI and CT scans. These showed multilevel DDD causing lumbar canal stenosis and nerve root compression at the disc levels from L2–L3 down to L5–S1 (Fig. 7). Significant disc degeneration and disc space narrowing was present at all levels (Fig. 7). The clinical and radiographic findings guided our choice regarding the levels of decompressions and fixation.

After signing an informed consent, through mini-open access, the patient underwent a right-sided MIS L2–L3 and L4–L5 facetectomies, laminetomies, and TLIFs; the same decompression and fusion procedures were carried out at L3–L4 and L5–S1 on the left side. A percutaneous pedicle screw fixation was then performed from L2 to S1 (Fig. 7). Postoperatively, the preoperative symptoms improved

Fig. 7 Sagittal T2-weighted MRI demonstrating multilevel lumbar canal stenosis from L2–L3 to L5–S1 (**a**); fluoroscopic AP (**b**) and lateral (**c**) images showing the multilevel percutaneous pedicle screws fixation, with four m-TLIFs, from L2 to S1

considerably and the improvement was maintained at the 24-month follow-up evaluation.

Results and discussion

Although the main goal of the present study is to focus on the surgical technique rather than on clinical outcomes data, it may be useful to report that, at a mean 23.6 months of follow-up, 11 patients (84.6 %) reported excellent or good results, according to the four-point outcomes scale proposed by Scheufler et al. [43].

In the present series, no neurological deficits secondary to misplaced pedicle screws or interbody cages were encountered. No CSF leaks were observed and no patients needed reoperation for persistent or recurrent symptoms. All patients underwent postoperative x-rays and multiplanar CT scans to check the position of screws and cages. According to the grading proposed by Kim et al. [21], two screws had encroachment of the medial pedicular cortex (3.1 %). No superior or inferior pedicle walls were damaged during the drilling of the facet joints, confirming the utility of early Kirschner wire insertion as cranial and caudal landmarks.

Surgical decompression and fixation techniques are commonly used to treat symptomatic patients suffering from lumbar degenerative disc disease and spondylolisthesis [35–40, 54, 55]; PLIF (posterolateral interbody fusion) [58] or TLIF [1, 13, 15, 17, 41, 57] are often stabilized with pedicle screws. In order to reduce approach-related surgical morbidity and collateral tissue damage while providing a more rapid functional recovery [27], MIS has progressively expanded [18, 20, 21, 25, 26, 29]. Following the first experience reported by Foley et al. [9, 10], MI-TLIF, performed through fixed tubes or, more recently, through expandable tubular retractors, has gained popularity [14, 16, 18, 21, 23, 25, 28, 30, 33, 34, 43, 45, 51, 52, 56]. A meta-analysis of fusion rates associated with MIS-TLIFs compares favorably to open TLIF techniques [56]. The use of endoscopes as well as of intraoperative EMG (Electromyography) monitoring [4] has been proposed to enhance visualization [16, 47] and increase intraoperative safety during MIS procedures. However, despite such increase in popularity and awareness of complication avoidance, misplacement of percutaneous pedicle screws remains an issue. Recently, Kim et al. [21] analyzed their series of 488 percutaneous screws implanted in 110 patients and reported an 11.1 % rate of pedicle penetration. Inferomedial pedicle wall penetration occurred in 37 % of patients and superomedial penetration in

3.7 %. They also suggested that pedicle convergent angle, obesity, and a greater multifidus cross-sectional area are factors affecting the accurate placement of percutaneous screws [21]. In addition to pedicle screw misplacement, dural and neural lesions are known to occur when performing MIS techniques [7, 8, 14, 22, 24].

According to reports in the literature [3, 7, 9, 10, 14, 16, 18, 20–23, 30, 33, 45, 51, 52], when performing a MI-TLIF or m-TLIF augmented with percutaneous pedicle screw fixation, after positioning the tubular or expandable muscle retractor, facetectomy and transforaminal cage insertion are usually performed before inserting the ipsilateral pedicle screws. This prevents the screw heads from reducing the available surgical space. Following the TLIF, the Jamshidi needles and K-wires are inserted into the pedicles, guiding the cannulated screws. Some authors have also advocated the removal of the tubular retractor followed by percutaneous introduction of the pedicle screws [3, 16, 33]. During this surgical step, the risk of a sharp instrument getting misplaced or slipping over a bony surface onto the exposed dural sac and causing a CSF leak and/or damaging the neural structures is substantial. This may induce the surgeon either to repeatedly check fluoroscopically the accuracy of the Jamshidi's placement over the pedicle's entry point or to use soft-tissue retractors to directly visualize the pedicle anatomical entry points [50]. Mummameni and Rodts suggested that the pedicle entry points be identified, probed, and tapped before performing the TLIF. In their description, bone wax is used to cover the entry points during the subsequent procedure and no K-wires are left in situ [28]. After performing the facetectomy, in order to safely and accurately insert the pedicle screws, AP and lateral fluoroscopic views are needed to make sure that the screws are inserted with the right lateral–medial and cranio-caudal trajectory into the vertebral body. The absence of a guiding K-wire could, in fact, facilitate a misdirected screw. The KCS technique allows for the use of only lateral fluoroscopy to insert the cannulated screws over the K-wires since their correct trajectory was already confirmed with AP and lateral fluoroscopy during their insertion. We believe that this represents a simplification of the surgical procedure. According to previously reported techniques, the drilling of the facet joint, even if performed using a microscope, may be associated with loss of orientation in the cranio-caudal direction and unintended violation of the cranial or caudal pedicular walls, particularly during the initial learning curve.

This is a more prominent risk when performing multilevel pedicle screw fixation with multiple m-TLIFs. In such cases, the intervening pedicle between the two disc spaces can be mistakenly drilled cranially and/or caudally. If such an event occurs, the risk of inferomedial cortical pedicle encroachment further exposes the exiting nerve root, which lies just underneath the lower edge of the pedicle, to potential damage caused by the instruments used to probe the pedicle and insert the screw.

In Kim's experience [21], 30 % of misplaced screws were at the S1 level, 26.5 % at L3, 23.1 % at L5, 19 % at L4, and 16.6 % at L2.

In single-level MI-TLIF, Shunwu et al. [47] preferred to insert the pedicle screws through a fixed tube before carrying out the discectomy and TLIF. However, we agree with the majority of authors [9, 10, 14, 16, 18, 21, 25, 28, 30, 33, 43, 45, 51, 52, 56] who suggest that such techniques may significantly reduce the available surgical space, particularly when an expandable tubular retractor is not used. Isaacs et al. proposed that the tubular retractor be removed after performing the m-TLIF and before inserting the pedicle screws. These were placed using a modified technique based on the insertion of all four K-wires at the index level under AP fluoroscopic control after performing the TLIF. Fluoroscopy was then turned to a lateral position and the procedure was continued [16]. However, even such techniques do not mitigate unexpected neural or dural injuries in the already exposed bony facet joint's area. Certainly, new instrumentation allowing insertion of the transpedicular screws without their heads at the beginning of the procedure, and attaching the heads after having performed the MI-TLIF, may be helpful [46]. In our experience with the KCS technique, we never had to remove the K-wires to place and expand the retractor to insert pedicle screws. Conversely, keeping the K-wires under direct visualization (Fig. 4) at the sides of the index facet joint to be drilled was a useful landmark in maintaining orientation.

We prefer to use the KCS technique over the technique of removal and coverage of the entry site with bone wax. This allows for better recognition of the pedicles during the subsequent facet joint drilling and also avoids the loss of clear visualization of the pedicles' entry points due to the drilled bone dust coating the wax. Moreover, we feel that the direct visualization of the K-wires entering the pedicles is a more reliable landmark during the drilling of the facet joint. In patients with degenerative changes, the superior facet is often distorted because of osteoarthritis and can no longer be a reliable anatomical landmark [48]. During MI-TLIF, if the degenerated superior facet joint is not completely removed, which is not uncommon, particularly in cases where the tubular retractor is directed more medially to perform a central canal stenosis, there is a risk that sharp instruments might slide over the distorted articular bone into the neural structures during percutaneous screw insertion using the standard technique. In order to avoid the above risks, Scheufler et al., after performing the MI-TLIF, angulated the 18-mm fixed tubular retractor to directly visualize the pedicle entry point and carry out a safe screw insertion next to the open canal. They did not use the standard fluoroscopy-guided percutaneous pedicle screw insertion technique in order to "avoid plunging into the open spinal canal with instruments" [43].

Dhall et al. observed that many maneuvers performed during MIS-TLIF are not intuitive and that the dearth of anatomical landmarks could lead to severe complications. As a result, the inexperienced surgeon working through the tubes is at risk for causing neurological injuries [8]. In addition to neural injuries, dural lacerations with CSF leaks can occur [7, 14, 22, 24].

Cage migration has also been reported as a complication of MIS procedures performed through unexpandable tubular retractors [24]. We have not experienced such a complication in the present series. It is our belief that expandable retractors provide a wider surgical field, which allows, using a microscope, better visualization for performing adequate decompression, disc space preparation, and interbody cage placement.

Recently, neuronavigation has also been proposed as a useful adjunct to safely insert pedicle screws, both percutaneously and during open techniques [6, 53]. Although we have the facility to use fluoronavigation, we did not use it in this series because of the need to acquire new registration data for each spinal level treated.

Shin et al. proposed the routine use of navigated guide tubes, which may represent a significant technological advancement. This is a new tool, utilizing only CT-guided navigation, which may allow for placement of mini-open pedicle screws without using K-wires [46]. The screws, without their heads, can also be inserted before removing any bony structures and exposing the neural structures. The use of only one navigated instrument to tap, drill, and insert screws can increase efficiency. However, such potential advantages, which Shin et al. noted in a series of only 10 patients, need to be validated in a larger series.

In our experience, the use of an expandable retractor through a Wiltse-type approach allowed us to visualize, in the same field, both the cranial and caudal pedicles entry points, as well as the facet joints to be removed. This obviated the need to intraoperatively adjust the retractor position to visualize the involved bony elements, a commonly reported requirement with fixed tubular retractors.

We did not experience any intraoperative complication and the operative time in our series of multilevel cases was similar to that reported by other authors [43].

Although this study's main goal is not to focus on clinical outcome, at a mean 23 months of follow-up, all patients reported postoperative clinical improvement in keeping with known data in the literature [7, 18, 23, 33, 43–45, 47].

The reported clinical benefits of minimally invasive approaches are counterbalanced by an increased x-ray exposure for both the surgeon and the patient. Bindall et al. registered a mean fluoroscopy time of 1.69 min (range 0.82–3.73) per case [4]; Peng et al. reported a fluoroscopic time of 105.5 s for MIS TLIF surgery versus 35.2 s for open procedures [33]; Kim et al. reported a fluoroscopic time of about 30 s per single screw [21]. These estimates, calculated per single- and double-level procedures, have to be adapted to multilevel cases, with a proportional increase. Our most complex case (10 transpedicular screws and four m-TLIFs) required 456 s of fluoroscopy. These times compare favorably with the estimates calculated by Kim et al. [21].

Even if the overall fluoroscopy time using our proposed technique is similar to previous reports [4, 21, 33], the KCS technique may improve intraoperative safety and efficiency by significantly reducing the risk of neural injury or durotomies in the exposed spinal canal during pedicle screw insertion.

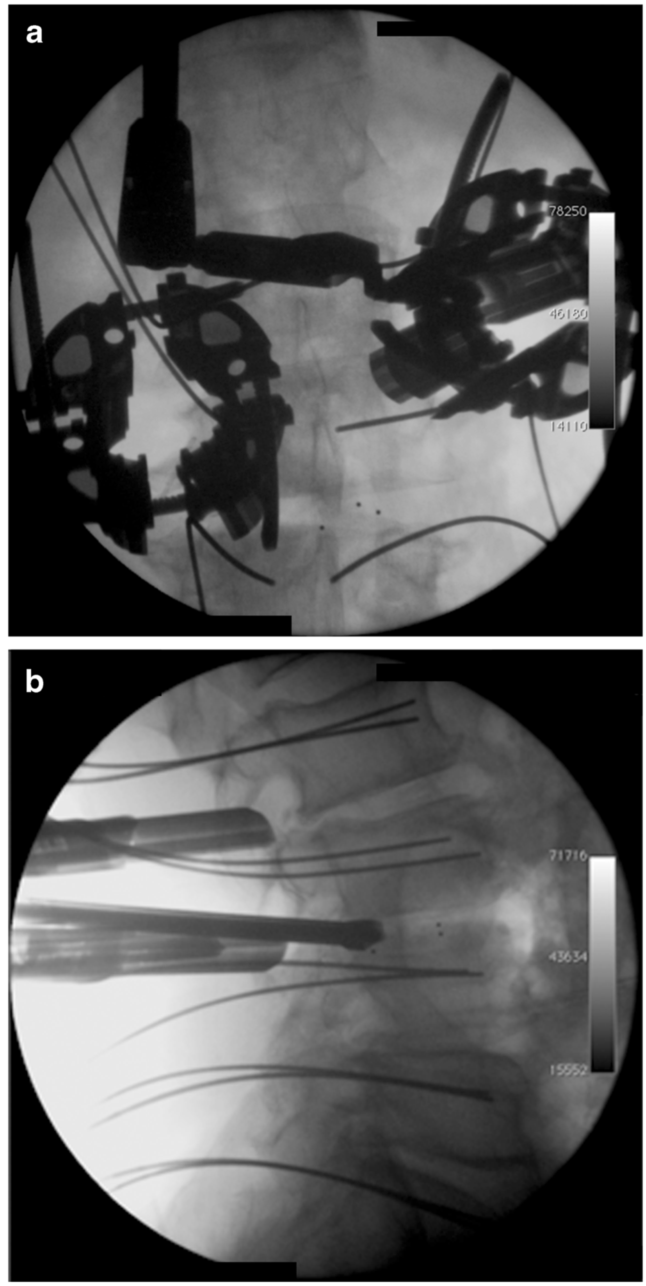

Fig. 8 Fluoroscopic AP image showing two expandable tubular retractors placed on either side in between the K-wires previously inserted at all levels (**a**); fluoroscopic lateral image showing a carbon-fiber cage inserted through the m-TLIF approach and all K-wires (**b**)

The multilevel cases presented in this paper highlight two main advantages of the KCS technique. First, during the microsurgical facetectomy, the two K-wires within the expandable retractor allows the surgeon to visualize the position of the cranial and caudal pedicles, thus maintaining proper orientation (Fig. 4). Second, early placement of K-wires at every level before removing the facet joint allows for safe and accurate placement of the screws after performing the m-TLIFs, without incurring the risk of injuring the exposed nerves and dura (Fig. 8). Such advantages apply also to obese patients or to those with greater multifidus cross-sectional area, conditions which can be potential risk factors for percutaneous screws misplacement [21].

We are aware of the limitations of this study: it is based on a small series, with a short follow-up. Yet, to our knowledge, no comparison with a similar cohort of patients treated by open technique has been performed. Another criticism to our work could be the lack of precise identification of the K-wire's position within the pedicle, in the cranio-caudal direction. Therefore, there remains the possibility of inadvertently drilling the cranial or caudal pedicular wall, despite using the KCS technique. However, this limitation not only applies to the currently described technique; it is even worse when the K-wires are not left in the pedicles since there is no intraoperative landmark. Certainly, further studies focusing on the technical aspects of multilevel PPSF and m-TLIF(s) are needed to confirm our results.

Conclusion

In conclusion, we demonstrate with intraoperative pictures the utility of a simple technique to increase safety and surgical efficiency during multilevel percutaneous pedicle screw fixation and m-TLIFs.

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Comments

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Lumbar fusion remains the gold standard treatment for lumbar instability. Despite current technological advancements, the "TLIF" technique stands as the premier option for treatment. Over the last few decades, the approach has seen progress through avoidance of the midline opening, while maintaining the same outcome.

The present article offers a feasible option for mini-open TLIF using the pedicle-based "Kirschner-Cage-Screw (KCS)" technique and displays a concise series of cases and literature review as support. Notwithstanding their lack of reported complications, we encourage meticulous care during and after the insertion of K-wires to avoid vascular or dural injuries.

Currently, we perform the same procedure using a navigated guide tube to avoid the complications related to K-Wire insertion. This has proven to be an equally safe procedure.

However, we consider the authors' technique to be a viable and safe option for TLIF procedures in spine centers globally.

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Mini-open multilevel TLIFs have become popular to achieve correction and stabilization of degenerative lumbar segments. However, multilevel TLIF through small surgical approaches as well as the associated pedicle screw stabilization through percutaneous approaches are technically demanding techniques with a flat learning curve, high x-ray exposure, and a high potential for misplaced pedicle screws. Placement of percutaneous pedicle screws before decompression and TLIF often results in a more tricky retractor placement due to the space-occupying screw heads. On the other hand, accidental violation of the pedicles during facetectomy or dura/nerve injuries due to slipping screws during placement after decompression are considerable risk factors in cases where the decompression of the spinal canal and the TLIFs are performed before placement of the screws. The authors describe a little but useful "nuance" of the surgical technique which helps to overcome these issues. Their "Kirschner Wire-Cage-Screw (KCS)" technique just changes the sequence of the different surgical steps. Placing the K-wire before decompression and TLIF minimizes the risk of pedicle violation during facetectomy and keeps the surgeon oriented about the pedicle borders. The K-wires leave enough space to adequately position the retractors during decompression and cage insertion. Placing the screws at the end of the procedure using the K-wires as guides minimizes the risk of screw misplacement. In a series of 13 patients who were operated on with this technique, the authors could show the safety of this technical approach. This is a useful and interesting article for those readers who are in the early phase of their learning curve for multilevel TLIFs. In addition, it gives a comprehensive review of the current literature about this topic.