4.2.4 Mini-open and percutaneous pedicle instrumentation and fusion

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1 Historical perspective

Posterior instrumentation and fusion techniques performed via a standard open approach with a midline lumbar incision and subperiosteal muscle dissection are associated with the risk of iatrogenic soft-tissue and muscle injury. Many recently published studies have confirmed approach-related changes affecting the paraspinal muscles and their effect on clinical outcomes [1–3]. Kawaguchi et al [2] highlighted the impact of protracted retraction times and increased pressure on the paraspinal muscles. Intraoperative multifidus muscle biopsy specimens showed histopathological lesions, the development of which was dependent on retraction time and the pressure induced by self-retaining retractors during posterior lumbar surgery. Gejo et al [1] evaluated the influence of posterior surgery muscle damage on clinical outcome. These authors found significant positive correlations between retraction time and the severity of muscle injury, decreased muscle strength, and magnitude of persistent low back pain three and six months after surgery. Using CT scans, Sihvonen et al [3] examined a large patient population with a long-term follow up after previous lumbar spine surgery. They concluded that patients with the worst clinical outcomes were those for whom electromyographic (EMG) studies and paraspinal muscle biopsies respectively revealed poor performance tests and local denervation atrophy. As a consequence, surgeons have endeavored to develop alternative techniques to reduce muscle damage to the paraspinal musculature and to improve the patients' clinical outcomes.

Magerl [4] pioneered minimally invasive instrumentation of the spine, and in 1982 used percutaneous pedicle screw insertion into the spine. In trauma settings, he combined pedicle screws with external fixation in the lower thoracic and lumbar spine. However, this technique was associated with high infection rates and was poorly tolerated by the patients.

A subsequent modification of this procedure was introduced by Mathews and Long [5] in 1995. They inserted pedicle screws with longitudinal connectors beneath the skin, but within the subcutaneous superficial plane. The risk of infection was thereby reduced, but as it was an inherently mechanically weak construct, this technique led to high nonunion rates. It was also uncomfortable for patients, and ultimately did not gain widespread approval.

Foley [6, 7] presented a system for placing percutaneous screws and rods in the submuscular plane, which was made possible by using screw extension sleeves and a unique rod insertion device.

In the treatment of degenerative disc disease, Cloward [8, 9] was the first to consider that posterolateral fusion (PLF) alone was insufficient, and that it was associated with an unacceptably high nonunion rate and symptom recurrence. He therefore proposed interbody fusion using structural bone autograft, a procedure that is commonly referred to as posterior lumbar interbody fusion (PLIF). There are several clinical advantages of PLIF over instrumented PLF. These include higher fusion rates, more complete decompression of the spinal canal and nerve roots, improved biomechanical properties of the construct, and restoration of intervertebral height in the case of segmental lordosis. Despite all these advantages, PLIF remains a technically demanding procedure that necessitates the removal of the posterior stabilizing ligamentous structures and frequent retraction of the neural elements.

The transforaminal lumbar interbody fusion (TLIF) is a different concept, designed to achieve the same goal, ie, a circumferential lumbar fusion through a single posterolateral incision that is performed in a less traumatic manner. First described by Harms and Jeszenszky in 1998 as an open procedure [10], TLIF approaches the spine more laterally and thereby preserves more of the posterior ligamentous and bony complex, and certainly requires less retraction of the nerve root and thecal sac. In modern-day surgery, it has now become a well-established technique associated with good clinical outcomes, high fusion rates and a low incidence of complications, and has more recently been applied in minimally invasive spine surgery (MISS) [11, 12].

In 1994, Foley and Smith [13] introduced a unique tubular retractor system which was initially designed for microdiscectomy, and that is composed of a series of sequential dilators to help split the muscle working corridor in an atraumatic fashion, to allow surgical access. In 2003, adaptation of this non-expandable tubular retractor system and subsequent expandable tubes have led to the concept of minimally invasive TLIF (misTLIF) [14].

Over the last decade, there has been a significant evolution and expansion in performing these original techniques of PLIF or TLIF in a minimally invasive fashion [15–18]. Today, less traumatic instrumentation techniques have now become established as reliable, and are regularly performed as a method of choice by many spine surgeons, practicing MISS, in treating a wide spectrum of spinal disorders.

In the following chapter, the terminology connected with minimally invasive strategies will be discussed together with detailed surgical techniques for performing mini-open visual and nonvisual misTLIF.

2 Terminology

Posterior approaches to the spine can be classified by their degree of invasiveness, ie, i) open; ii) mini-open (visual or nonvisual); or iii) transmuscular, more widely known as the "percutaneous" approach.

A midline standard open exposure offers reasonable access with good visualization of the target structures and surrounding anatomy. This approach allows for the direct visual placement of pedicle screws, interbody cages, and bone graft. It is performed, however, to the detriment of certain key factors: operative time, blood loss, and damage to the paraspinal soft tissues, which results in scarring and subsequent reduction in postoperative muscle function, are all increased. There are also potentially negative consequences on the short- and long-term clinical outcomes.

Mini-open or minimal access "visual" techniques utilize soft-tissue dilators and expandable tubular retractors. This internervous muscle splitting or Wiltse approach [19] significantly reduces posterior soft-tissue and muscle trauma, and at the same time allows for direct visualization of up to two spinal motion segments. Furthermore, the approach enables direct visual placement of pedicle screws, interbody cages and bone graft.

The mini-open (nonvisual) or percutaneous approaches, the latter more precisely referred to as a transmuscular approach, utilize sequential tubular dilators followed by extension screw sleeves and rod insertion devices to assist in the insertion of the pedicle screws and rods (**Fig 4.2.4-1**). These pedicle screw fixation nonfusion techniques are performed indirectly, ie, without direct visualization of the target area, and are entirely dependent on image intensification, or computer-assisted 3-D navigation (see chapter 1.6 Computer-assisted navigation for minimally invasive spine surgery). Therefore, these techniques offer a truly minimally invasive approach that causes the least access- and retraction-related damage to the surrounding soft tissues. However, to perform either a PLIF or TLIF, interbody fusion has to be achieved via a separate working port or tube. Other alternative interbody fusion approaches include the extralateral interbody fusion (XLIF, or translumbar discectomy and fusion; see chapter 4.3.3 The lateral approach to the lumbar spine) or anterior interbody fusion technique (ALIF; see chapter 4.3.1 Minimally invasive anterior midline

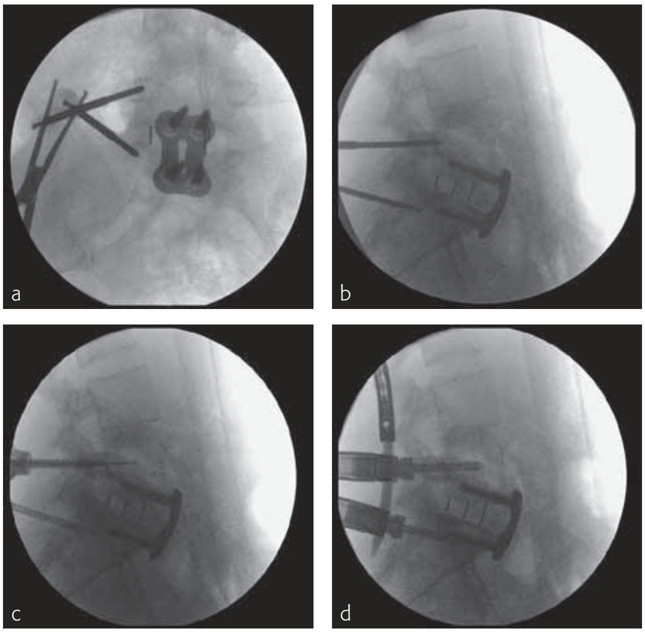


Fig 4.2.4-1a–d
a AP image intensification of L5/S1 showing that the tip of the Jamshidi needles have not breached the medial pedicle wall. Note the divergent position of the needles.
b–c Lateral image intensifcation confirming that the needles have been advanced into the posterior vertebral body before a guide wire is threaded, followed by tapping of the pedicle.
d Lateral image intensification showing that an appropriate length precountoured rod has been secured in position into the polyaxial heads of the pedicle screws.

approach to the lumbar spine and lumbosacral junction). Subsequent supplementary posterior segmental fixation helps secure the facets in extension, and thus restores the integrity of the posterior tension band in order to minimize interbody graft loading, and therefore improves the outcome of an interbody fusion.

3 Patient selection

Posterior mini-open and transmuscular pedicle screw instrumentation and fusion techniques can be used for treating a large number of different spinal pathologies, eg, degenerative disorders, trauma, tumors, infections and certain select cases of spinal deformity [20]. The main goal is to minimize collateral damage to the posterior soft tissues. However, it has to be kept in mind that patient selection, indications and subsequent surgical techniques remain the same, irrespective of the choice made between a standard open or minimally invasive approach. For the most part, degenerative disc disease (DDD) resulting in discogenic low back pain, lumbar spinal lateral recess stenosis, and degenerative spondylolisthesis leading to segmental instability are the main indications for the application of these approaches.

In the degenerative setting, misTLIF has been established as a safe and reliable technique for performing single- or double-level surgery [21], and in some cases revision surgery [22]. Therefore, circumferential lumbar fusion through a single-stage posterior mini-open approach is readily achievable in this way. In some patients, the disc space is much too collapsed to accommodate an interbody cage; thus in these cases, the mini-open PLF will suffice.

3.1 Primary indications for misTLIF

- Primary DDD causing discogenic low back pain with or without disc herniation
- Segmental instability causing low back pain with or without nerve root compression
  - Lytic or degenerative instability
  - Lytic or degenerative grade I or II spondylolisthesis
  - Traumatic instability
  - Postoperative or iatrogenic instability following excessive facetectomy or removal of the pars interarticularis
  - Unilateral facet-joint dysplasia or tropism
- Previous surgery causing low back pain with or without nerve root compression
  - Post-discetomy syndrome
  - Post-laminectomy syndrome
- Interbody disc space collapse with exit foraminal nerve root compression secondary to:
  - DDD
  - Lateral recess stenosis
  - Lytic or degenerative spondylolisthesis
  - Postdiscectomy or laminectomy syndrome
- Treatment of pseudarthrosis where interbody fusion is required.

3.2 Contraindications for misTLIF

- Treatment of sagittal and coronal deformities of the lumbar spine
  - Degenerative kyphosis/scoliosis
  - Postlaminectomy kyphosis
- Multilevel disease (> 2)
- Deep-seated pelvis with high iliac wing—iliac crest osteotomy feasible to help gain surgical access
- Morbid obesity.

4 Pros and cons

The main advantage of MISS over the open procedures is its distinct preservation of the posterior soft tissues and paraspinal muscles. However, presently there are no level 1 randomized control trials investigating the differences in outcome between misTLIF and open TLIF. In the literature, the remaining differences between these two procedures are predominantly observed in their immediate intraoperative and short-term clinical outcome results [23, 24]. Conversely, the long-term clinical outcomes appear comparable [23].

4.1 Advantages

Intraoperative advantages:

- Reduced approach-related soft-tissue and paraspinal muscle injury
- Reduced blood loss
- Reduced length of surgery
- Reduced intraoperative complications, ie, dural tear, neural and vascular injuries, implant malpositioning.

Immediate and short-term advantages:

- Reduced postoperative pain and analgesic intake
- Reduced total blood loss (and drain blood loss), obviating the need for blood transfusion
- Allows for early mobilization and reduced need for rehabilitation
- Reduced length of hospital stay, possibly performed as day surgery
- Reduced early complications, eg, wound infection.

Long-term advantages:
- Decreased local denervation and atrophy of paraspinal muscles
- Increased fusion rate (a large number of studies suggest that this may be related to the more frequent use of bone morphogenetic proteins (BMPs) and therefore this requires re-evaluation)
- Satisfying cosmetic effect
- Early return to work and sports activity
- Reduced adjacent-level DDD due to preservation of soft tissue and posterior elements.

4.2 Disadvantages
Intraoperative disadvantages:
- Training and certification required
- Limited to one or two levels; in addition, limited multisegmental surgery is unachievable
- Limited visualization of the target area anatomy
- Steep learning curve compared to open surgery
- Increased x-ray exposure time, however, this can be minimized with the use of computer-assisted navigation
- Reconstructive surgery of long kyphotic and scoliotic deformities unachievable
- Morbid obesity makes surgery impossible.

Short- and long-term disadvantages:
- More extensive soft-tissue dissection when considering proximal or distal extension of fusion.

5 Preoperative planning and positioning

The significance of preoperative planning remains extremely high, and is strongly correlated with clinical outcomes in MISS. A limited working corridor permits only a partial view of the potentially complex target pathology. Because only a limited number of anatomical landmarks are exposed, accurate preoperative CT scans and MRI are essential adjuncts in ensuring the accurate positioning of the implants. This accuracy may be noticeably improved with the use of intraoperative 3-D computer-assisted navigation.

Preoperative planning starts with proper patient selection. Information obtained from the patient's history, physical examination, clinical diagnostic testing and imaging studies (eg, MRI, CT scan, static and dynamic x-rays) should be sufficient to determine the appropriate level or levels requiring surgery. If any doubts remain, then electromyography, nerve conduction studies (NCS), discography, or selective facet joint and nerve root injections may be useful preoperative adjuncts to help establish a final diagnosis.

Standing AP and lateral plain x-rays of the whole spine as well as the pelvis and femoral heads, and also flexion/extension dynamic x-rays are extremely useful. They provide basic information about important parameters concerning the spine, such as sagittal and coronal spinal balance, vertebral anomalies, segmentation anomalies, segmental and global lordosis, intervertebral disc-space height loss and foraminal height loss. MRI provides accurate views of the soft tissues and is a useful means of determining the location and extent of disc herniation, or stenotic elements that impinge on the neural structures. It is also essential in planning the exact level of the spinal decompression, implant size, length and position in relation to the surrounding anatomy. Furthermore, it is useful in cases of revision surgery in determining the exact location and extent of scar-tissue formation. In contrast, CT scans give clearer definition of the bony elements of the spine, and can provide additional information about pars defects, bony stenotic elements, osteophytes, the 3-D characteristics of deformities, and previous fusion procedures. Exact pedicle screw measurements, ie, diameter, length, and orientation may be evaluated on CT scans as well as on MRI using calibrated tools that are integrated into interactive software radiology modules.

Because of the limited access and intraoperative views, it is crucial to adjust the patient's preoperative on-table position accordingly, and to accurately determine the surgical corridor. Additional factors, such as the optimal placement of image intensification equipment, navigation devices, television monitors, and microscope, should also be taken into full consideration because these utilities will ultimately deplete the surgeon's essential operational space around the operating table. Spending invaluable time on these considerations at the preoperative stage translates into time saved during the operative procedure.

The patient may be positioned prone on a Montreal mattress and radiolucent frame table. Both arms are abducted at 90° and secured with arm pads in a symmetrical manner. In the event of the patient presenting with hyperlordosis, this causes closing of the posterior intervertebral disc spaces and makes the procedure more challenging. Furthermore, fusion in this position may overload the facet joints. On the other hand, fusion in a kyphotic position, especially when performing a bisegmental fusion, results in an unacceptable flat-back surgery syndrome. Placing both the hips and knees in a semiflexed position helps eliminate a flat-back posture. For a more convenient working corridor, the present authors prefer to keep the desired intervertebral disc space almost perpendicular to the floor, which is especially invaluable at the L5/S1 level. General anesthesia is routinely performed, and a single dose of preoperative antibiotic prophylaxis is administered approximately 30 minutes before the skin incision. A standard mandatory pre incision surgical checklist is routinely made in order to minimize any surgery-related complications.

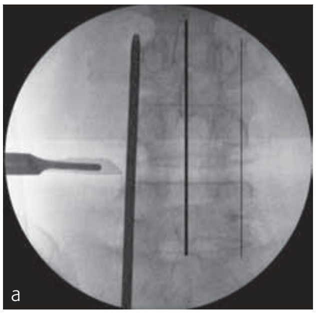
6 Surgical technique

6.1 Mini-open misTLIF or PLF

The senior author prefers a mini-open visual technique for performing a misTLIF. This ensures direct visualization and decompression of the target pathology, with reduced image intensification time, the possibility to perform a full decortication of the bony elements, and the subsequent execution of a posterolateral fusion. In this regard, this technique allows for an absolute 360° motion segment fusion.

After aseptic preparation and draping of the patient, the skin incision is planned using AP image intensification and marking of the skin. For each specific motion segment, the amount of lordosis of the gantry must be adjusted so that the endplates are seen in parallel. The midline spinous processes and lateral border of the pedicles are used as anatomical guidelines (**Fig 4.2.4-2**). The skin incision should be positioned approximately 1.0–1.5 cm lateral to the outer pedicular line or 4.0–4.5 cm lateral to the midline and bisected at the level of the corresponding facet joint complex, if surgery involves a monosegmental fusion, or at the middle of the pedicle if a bisegmental fusion is planned. When using expandable soft-tissue retractors, a 3–4 cm craniocaudal vertical incision will suffice for single-level, and should be extended to 5–6 cm for double-level surgery.

The senior author's preference is to start with the less symptomatic or asymptomatic side first. After the skin incision, the subcutaneous and fat-tissue layers are incised from the underlying fascia inferiorly until the iliac crest is digitally palpable. This optional subfascial incision is made to harvest iliac crest autograft bone to help enhance the bone fusion. Bone wax is used to stop the bone from bleeding, a drain is securely positioned, and the fascia is approximated with a running suture. Using the same skin incision, a second medially orientated subfascial incision is performed for tubular retractor placement. A medially orientated blunt digital dissection between the multifidus and longissimus muscles is made according to the Wiltse internervous muscle-splitting approach [19]. The soft tissues between the palpable transverse processes are gently swept aside in a cephalocaudal manner. Then sequential soft-tissue dilatators are docked accurately over the desired facet-joint complex, which is confirmed under AP and/or lateral image intensifier control (**Fig 4.2.4-3**). Appropriate-length tubular retractors are firmly inserted and medially angulated for optimal trajectory. The dilators are removed and the working port is securely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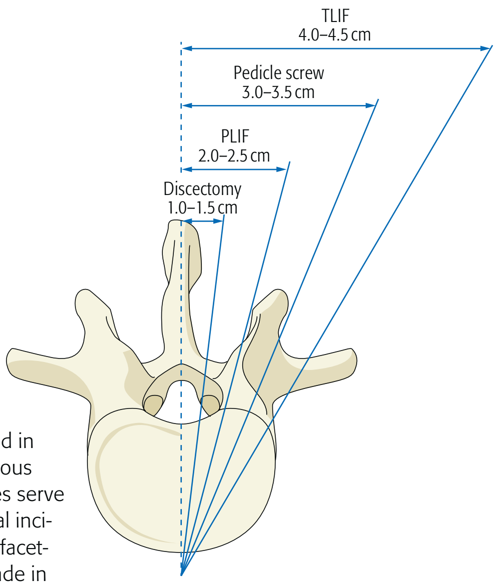

b

Fig 4.2.4-2a–b
a AP intraoperative image intensification used in helping plan the incision. The midline spinous processes and lateral border of the pedicles serve as anatomical guidelines. A 3–4 cm vertical incision should be positioned adjacent to the facet-joint complex, represented by the knife blade in the case of a monosegmental L4/5 TLIF.
b Representation of the variation in transverse plane distances from the vertical midline of the spine depending on the planned surgical procedure.

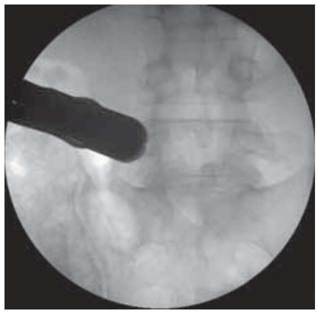

Fig 4.2.4-3 AP image intensification confirming that the tubular retractor is accurately docked over the desired L4/5 facet-joint complex.

fastened to the table frame and adjusted with a flexible clamp. The retractor is gently expanded as required in a cephalo-caudal direction to fully visualize the target segment, which is confirmed by image intensification before proceeding further (**Fig 4.2.4-4**). Appropriate length mediolateral distraction blades are adjusted to provide maximal visualization of the surgical working area. The remaining soft tissues are removed using electrocautery and pituitary rongeurs down to, but not beyond, the intertransverse membrane. The facet joint and transverse process are identified and decorticated using a high-speed drill. The pedicles are opened under direct visualization by gently introducing a pedicle awl and finder, then palpated with a pedicle feeler and tapped (**Fig 4.2.4-5**). The exact pedicle entry point is located at the mamillary process, which corresponds to the midpoint junction where the transverse process meets the superior articular process of the facet joint. The appropriate length, diameter and trajectory of the pedicle screws that have been preplanned on preoperative CT scans or MRI are inserted and confirmed under AP and lateral image intensification, or using computer-assisted 3-D navigation. An appropriate length rod is inserted and tightened temporarily in a semidistracted position in order to help open up the interbody disc space. Iliac crest bone autograft bulked with a bone extender, eg, demineralized bone matrix (DBX) or tricalcium phosphate (TCP) granules, is carefully placed over the decorticated transverse processes, pars interarticularis, and facet joint. It is generally considered best to avoid using

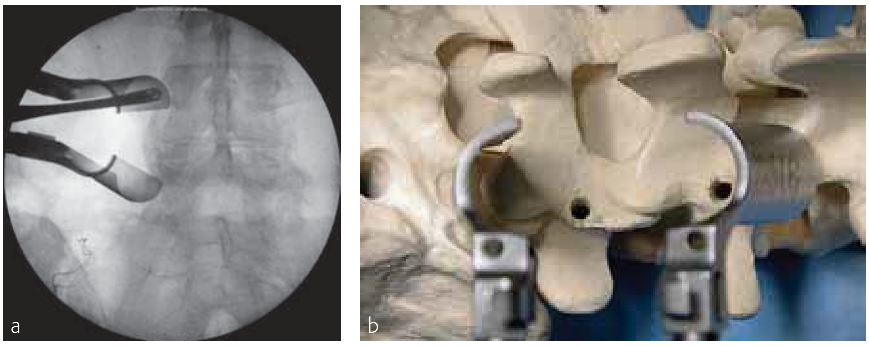

Fig 4.2.4–4a–b
a AP image intensification showing that the retractor has been expanded appropriately in a cephalo-caudal direction to visualize the target L4/5 segment. A pituitary rongeur has been used to confirm the position of the superior transverse process.
b A spine model showing mini-open direct visualization of the posterolateral L4/5 facet-joint complex and transverse processes.

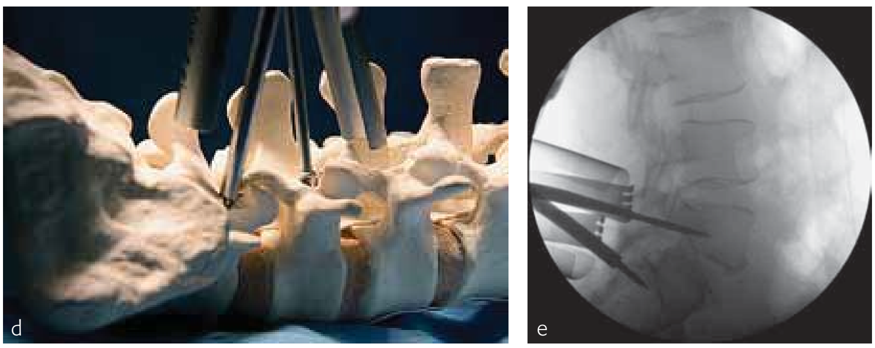

Fig 4.2.4-5a–e The pedicle entry points are directly visualized and entered using a pedicle awl and finder. The integrity of the pedicle must be confirmed both clinically by palpating with a pedicle feeler, and radiologically by using intraoperative AP and lateral image intensification.

BMPs because of their highly angiogenic characteristics, which may result in undesirable but temporary postoperative inflammatory radiculitis.

The exact same steps are repeated on the contralateral, symptomatic side, except for harvesting of the iliac bone autograft. The pedicle entry points are plugged with bone wax to prevent blood from continually oozing into the working field. Then the retractor blades are angled medially and the working zone over the facet joint is cleared out of its remaining soft tissue. Using a combination of bayoneted Kerrison rongeurs, osteotomes, and a long-tipped high-speed drill, a unilateral subtotal facetectomy is performed under direct visualization using a head light source, surgical loupes, or microscopic assistance.

The senior author considers that two different modified techniques are available to perform a comprehensive decompression of the spinal canal and nerve roots according to the patient's clinical symptoms and preoperative plan. The first technique comprises the "Out-In", or extracanal technique, which is the true TLIF technique that is principally indicated in situations with a paracentral, lateral or extra-lateral disc herniation or foraminal osteophytic pathology associated with segmental DDD or instability. A unilateral, subtotal facetectomy is performed with preservation of the ligamentum flavum in most cases. The triangular "working space" is made up of the exiting nerve root laterally, the dura alongside the traversing nerve root medially, and the superior border of the inferior pedicle. The exiting nerve root is identified and protected with a Neuro Patty. Bleeding from the epidural veins is cautiously cauterized with a bipolar forceps, thus exposing the intervertebral disc that is visualized at its posteromedial aspect, ie, the axilla of the exiting nerve root.

While protecting the neural structures, a scalpel blade is used to carefully incise the annulus fibrosus and as much of the disc material that can be removed down to the bleeding endplates. The bony endplates are prepared methodically using a variety of bayoneted cartilage shavers, curettes, and rasps. During this process, sequential distraction of the contralateral screw-rod construct is applied to help achieve an adequately wide opening of the interbody space. In order to improve trial and final cage access into the intervertebral space, the posterior marginal endplates and osteophytes are removed using a combination of osteotomes, Kerrison rongeurs, or a high-speed drill. Then the disc space and lateral recess is carefully examined using a neurological hook to remove any residual disc material or bony endplates.

The other decompression technique comprises the "In-Out" or intracanal technique. This technique is especially useful when, on the basis of the clinical symptoms and subsequent preoperative planning, bilateral spinal canal and nerve root decompression is desired, which can be readily performed via an ipsilateral approach in order to reach the contralateral pathology (see chapter 4.2.1 Bilateral decompression in lumbar spinal stenosis through a microscope-assisted monolateral approach). In this case, a thorough complete facetectomy and removal of the ligamentum flavum from its laminar attachment is performed. For improved visual access, the patient is tilted away on the table frame and the retractor is angled more acutely in a medial direction. The base of the spinous process and inferior aspect of the contralateral lamina are undercut using a Kerrison rongeur and/or high-speed drill. When the dura is gently retracted, this maneuver permits direct visualization and decompression, ie, flavectomy and facet undercutting of the contralateral stenosis to reach the nerve root that is trapped beneath the lateral recess. The ligamentum flavum may be temporarily used to prevent iatrogenic neural damage when performing a posteriorly directed channel of decompression towards the lateral recess, and subsequently removed towards the end of the decompression. Following a satisfactory adequate decompression, a subtotal discectomy is performed as described above.

Using a combination of enlarging trial implants and fixed distraction of the contralateral screw-rod construct, the intervertebral disc space is comfortably enlarged to its natural size, which helps restore the normal physiological lordosis and neuroforaminal diameter. The appropriate size of the implant is confirmed by lateral image intensification (**Fig 4.2.4-6**) before placement of the cage, which is tightly pre-packed with bone autograft (from the iliac crest and/or decompressed local bone) and extended with DBX. Under image intensification, the curved interbody cage is carefully rotated into a position that is close to the anterior margin of the vertebral endplates to help achieve lordosis restoration and uniform apophyseal loading, and to prevent cage migration (**Fig 4.2.4-7**). The interbody disc space posterior to the cage is filled tightly with bone autograft and DBX.

Afterwards, the transverse processes and surrounding bone are decorticated with a high-speed drill. Final pedicle screw/rod instrumentation is secured in position, and the remaining bone graft and DBX is placed in the posterolateral gutter for the fusion. Uniform bilateral compression of the pre-contoured lordotic rod must be gently applied to the interbody cage to prevent unwanted intracanal implant and bone-graft migration. Finally, an angled nerve hook is used to confirm that both the traversing and exiting nerve roots are free of any soft tissue or bony compression. Once the final AP and lateral image intensification has confirmed the correct positioning of all the implants (**Fig 4.2.4-8**), the wounds are irrigated with saline, and the soft-tissue layers approximated with running sutures (**Fig 4.2.4-9**). A drain is generally not required due to the limited empty surgical dead space that has been created. Evidently, when the disc space is far too collapsed, a PLF rather than a TLIF will suffice, provided that the affected nerve roots have been adequately decompressed.

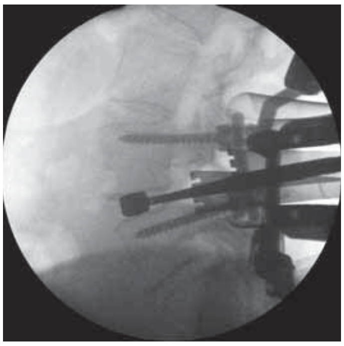

Fig 4.2.4-6 Lateral image intensification showing that an appropriately sized trial implant has been used for a L4/5 misTLIF.

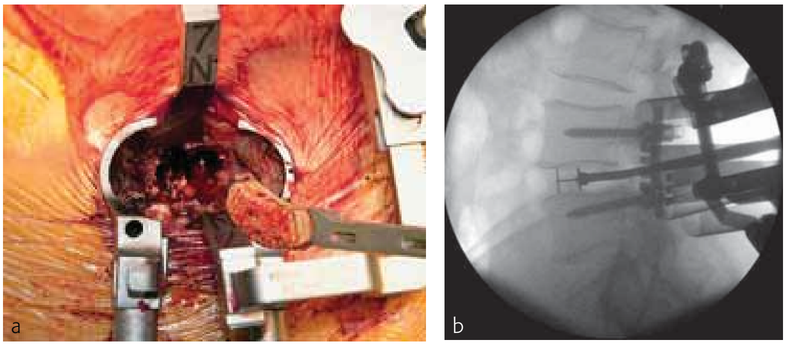

Fig 4.2.4-7a–b
a A definitive-size cage has been tightly packed with a mixture of bone autograft and DBX.
b Under lateral image intensification, the interbody cage has been rotated into a position that is satisfactorily close to the anterior margin of the apophyseal endplates.

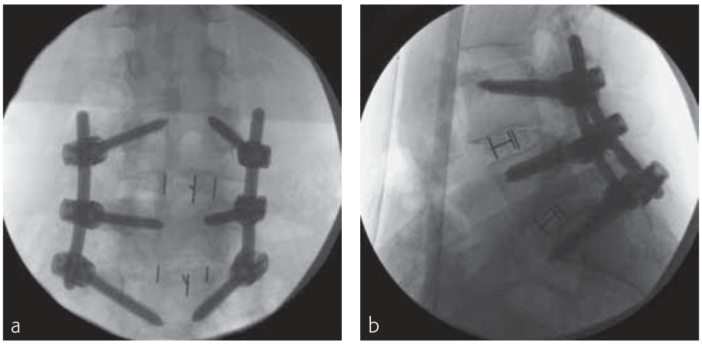

Fig 4.2.4-8a–b Final AP (**a**) and lateral (**b**) intensification images confirming the correct positioning of all implants, in this case showing a 2-level L4–S1 misTLIF.

Fig 4.2.4-9 Immediate postoperative closed wounds, in this case showing 4 cm long wounds after performing mini-open L4/5 misTLIF.

6.2 Mini-open nonvisual and transmuscular misTLIF

Alternatives to the mini-open visual misTLIF described above are the somewhat less invasive mini-open nonvisual and transmuscular misTLIF. The subtle variation in these techniques depends on the type of pedicle screw system that is employed, and therefore dictates whether the respective incision needs to be created via a single 2–3 cm long incision or multiple 1.5 cm stab incisions. Both these techniques of screw fixation are perceived as being the least invasive, but their major shortcoming is that they are both performed entirely "blind", and are thus wholly dependent on image intensification or computer-assisted 3-D navigation. Additionally, they are considered to be fixation nonfusion techniques; it is therefore mandatory to achieve interbody fusion using a different nonexpandable port or an alternative access for the fusion, eg, a tubular port for PLIF, TLIF, ALIF, or XLIF. In these cases, a 270° intervertebral interbody fusion can be achieved.

In the case of a misTLIF, there are no specific differences in skin incision planning, approach and fixation between these two techniques. Firstly, the pedicle screws are inserted before performing the interbody fusion. For a one-level fusion, and under direct AP image intensifier control or 3-D navigation, two separate 1.5 cm stab incisions (or one single 3 cm incision) are planned approximately 3–3.5 cm lateral to the midline of the spinous processes at the level of the corresponding pedicle (**Fig 4.2.4-2**). Once the skin and fascia have been incised in a Wiltse-type approach, a beveled Jamshidi needle is placed onto the transverse process by manual palpation and then gently maneuvered medially until it meets the superior articular process. The entry point for the pedicle screw is approximately at the 9.00 o'clock position on the left side (**Fig 4.2.4-1a**) and at 3.00 o'clock on the right side on the AP view. The image intensifier gantry may be tilted approximately 10° laterally to develop an "en-face" visualization of the pedicle. As for the mini-open visual TLIF, for each specific motion segment the amount of gantry lordosis must be adjusted so that the endplates are seen to be "in parallel".

Then the beveled Jamshidi needle is introduced medially through the pedicle until it reaches the posterior vertebral body wall without touching or breaching the medial pedicle wall (**Fig 4.2.4-1a–b**). Afterwards the projection is altered to the lateral view and the needle is gently advanced by another 1 cm. Moving the image intensifier projection between AP and lateral views will help to ensure the correct placement of the Jamshidi needle; rotating the bevel will also help guide the needle tip to the desired position. Then a threaded guidewire is inserted into the posterior vertebral body. After tapping for an appropriate length, the cannulated screw with the attached extension sleeves is inserted (**Fig 4.2.4-1c**), then a rod is introduced using a rod insertion device (**Fig 4.2.4-1d**) and distracted as required to help open up the intervertebral space opening, and temporarily tightened.

A nonexpandable tubular working port is inserted using sequential dilators and docked over the facet complex using maneuvers that are very similar to the technique described above. Both the "In-Out" and "Out-In" techniques of decompression are possible. Once the tubular port is perfectly positioned and securely tightened to a flexible table clamp, routine preparation of the disc space and decompression remains almost identical to that described above. At this point, contralateral distraction of the screw-rod construct is performed to improve access to the intervertebral disc space. Unfortunately, a direct view into the disc space is limited and frequent suboptimal contralateral disc space clearance remains a technical drawback. Endplate preparation and cage insertion remains indistinguishable from the mini-open visual technique. Once the appropriately sized cage prepacked with a mixture of local autograft bone and DBX or BMP has been inserted, the pedicle screw-rod construct is compressed uniformly on both sides. A drain is not routinely placed in this technique, and the soft tissues are approximated in layers using running sutures.

7 Postoperative care

- Thromboembolic prophylaxis with fractionated heparin until full mobilization is possible (usually 2 to 3 days)
- Two postoperative doses of antibiotic prophylaxis
- Mobilization on the first postoperative day with the aid of a physiotherapist
- No additional immobilization or brace is required
- Optional wound drain removed on the first or second postoperative day
- Wound dressings changed as required
- Check standing AP and lateral x-rays once the patient is independently mobile
- The patient is discharged on 2nd or 3rd postoperative day or when independently mobile
- The patient is advised to limit lumbar spinal movements for the first 3 months of surgery
- Gentle outpatient core stability exercises for up to 6 weeks, with no restrictions thereafter depending on patient capability
- Routine clinical assessment (Oswestry Disability Index [ODI] and visual pain analog scale [VAS]); and check plain x-rays at 3, 6, 12, and 24 months after surgery
- Optional CT scan 3–6 months after surgery.

8 Evidence-based results

Minimally invasive instrumentation and fusion techniques have gained increasing popularity in the last decade. Nevertheless, prospective randomized controlled trials comparing minimally invasive versus open techniques are so far lacking in the published literature. Most papers report retrospective case series, ie, class of evidence level III studies. For the most part, these limited studies report a trend towards reduced operative blood loss, shorter operating times and hospital stays in favor of misTLIF, but the results regarding long-term clinical and radiological outcomes between the two techniques appear to be equivocal.

In a quantitative meta-analysis on published studies (up to March 2008), Wu et al [24] reported two main clinical outcomes, ie, fusion rates and complication rates for both open TLIF and misTLIF in the treatment of symptomatic degenerative lumbar disease. A total number of 1028 patients with a mean age of 49.7 years (range 38–64.9) and a mean follow-up 26.6 months (range 6–46) were included in their statistical analysis. Spinal fusion, as defined by CT evidence of trabecular bone bridging or lack of motion on lateral flexion/extension x-rays, was observed in 90.9% of the open TLIF versus 94.8% of patients in the misTLIF groups. However, the use of BMP was significantly higher in the misTLIF group (50% versus 12%). Complication rates were reduced in the misTLIF (7.5%) compared to the open TLIF (12.6%) groups.

Dhall et al [23] published a well-designed case series with a long-term follow-up, comparing misTLIF versus open TLIF, performed via a standard midline lumbar incision and subperiosteal muscle dissection. Significant trends toward reducing estimated blood loss, operating times, and hospital stays were observed in the minimally invasive group. The mean estimated blood loss was 194 ml versus 505 ml, mean length of stay was 3 days versus 5.5 days, and mean operating time was 199 minutes versus 237 minutes in favor of the minimally invasive group. No statistically significant difference was observed in patient clinical outcomes measured by the modified Prolo scale.

Wang et al [22] compared the outcomes of misTLIF against open TLIF performed following previous open discectomy or decompression procedures. Statistically significant differences were observed in intraoperative and total blood loss, second day postoperative pain, and x-ray exposure times. The mean intraoperative and total blood loss was 291 ml and 316 ml respectively in the misTLIF and 652 ml and 799 ml in the open group. The mean second day postoperative back VAS was 22% in the misTLIF versus 43% in the open group. However, the mean x-ray exposure time was higher in the misTLIF at 73 s compared to 39 s in the open group. The authors reported a higher incidence of dural tears and superficial wound infections in the open TLIF group. No significant differences were reported in the operating times, or long-term clinical (Oswestry Disability Index (ODI) and VAS scores) and radiological outcomes.

9 Complications and avoidance / salvage procedures, learning curve

Much of the literature has reported reduced complication rates among the minimally invasively treated population groups. In Wu et al's meta-analysis of published studies [24], general complication rates were 12.6% for the open and 7.5% for the misTLIF groups.

Complications can be divided into those occurring during the intraoperative period, in the early postoperative period and those occurring later on. Dural tears with cerebrospinal fluid (CSF) leakage and radiculopathy were the most commonly reported intraoperative complications in both groups. However, because of a more lateral and physiological approach, neural element injuries are less likely to occur in the minimally invasive group. To prevent these complications, good visualization through accurately positioned working surgical corridors is essential. Additionally, vigilant protection of the neural elements has to be ensured at all times with the use of small cottonoid Neuro Patties. These serve to protect the dura and exiting nerve root, which are continually retracted during the discectomy, endplate preparation, and cage insertion maneuvers.

Open conversion in the case of dural injury with CSF leakage is contraindicated, and can be justified only in the event of severe damage. The buildup of lower volumes of CSF within the restricted free dead space coupled with the higher pressures generated by the surrounding intact muscles remain favorable factors for the sealing any incidental durotomies. The interrupted dura only rarely requires suture and repair. Additionally, a small piece of Duragen and fibrin glue may be used to stop the CSF leak. In the case of continuous leakage, tension sutures and a gravity drain may be employed.

Also, pedicle screw and interbody spacer malpositioning are frequently reported problems. Preoperative planning remains essential in avoiding these surgeon-related complications. Intraoperative biplanar image intensification is effective in confirming correct hardware positioning, but as an alternative, computer-assisted 3-D navigation may be used to improve accuracy. Specific nerve-root EMG monitoring can also be useful in detecting a breach of the medial pedicle wall caused by the screw.

Early postoperative complications, such as hematoma, superficial and deep wound infections, or general health complications (eg, postoperative stroke, pulmonary embolism, or chest infection), subsequent to a direct reduction in operating time and blood loss combined with early mobilization, may be reduced in minimally invasive cases but this can only be determined through prospective multicenter studies.

Pseudarthrosis and implant failures are considered late postoperative complications. According to Wu et al [24], fusion rates amounted to 90.9% and 94.8% for open and misTLIF respectively; the use of BMP in the misTLIF groups may explain the improved fusion rate. Complete intervertebral disc removal and careful endplate preparation is crucial in achieving high-quality interbody fusion. The utilization of iliac crest, versus local decompression autograft bone, versus DBX and BMP, are subject to continuing controversy. The senior author's preference is to use a combination of DBX mixed with iliac crest bone autograft because of the latter's excellent osteoinductive and osteoconductive properties. Achieving a sound posterolateral and interbody fusion will prevent the development of pseudarthrosis, and subsequent implant failure.

Implant failure may be secondary to poorly positioned implants and interbody cages, resulting in a deficient biomechanical setting or nonunion as a consequence of a poorly executed fusion. To this end, an accurately sized interbody spacer and correct placement within the anterior apophyseal rim plays an important role in both instances, restoring the physiological lordosis and conferring uniform loadbearing onto the interbody bone graft. A sturdy posterior tension band is dependent on the appropriate screw diameter, length, and position, as well as on the bone quality. All these factors may be predetermined on CT or bone density scans, or MRI prior to the operation. Both sagittally divergent and coronally convergent pedicle screws provide improved biomechanical strength to the construct.

The learning curve in performing a misTLIF is rather steep, but can be mastered without difficulty through proper training and certification followed by an approved training program. In order to achieve a sound fusion, meticulous attention to the correct biomechanical principles of the instrumented construct, in combination with careful preparation of the interbody disc space and/or the posterolateral gutters, will undeniably result in highly satisfactory patient clinical and radiological outcomes.

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10 Tips and tricks

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- The operating table can be placed in a reverse Trendelenburg position for better access and visualization of the L4/5 and L5/S1 disc spaces. The reverse Trendelenburg position will orient the disc spaces of L4–S1 perpendicular to the floor and facilitate visualization and instrumentation.
- After preparation and draping, a superficial percutaneous needle (one to two inches off midline) is placed along the lateral margin of the pedicles on the AP image intensifier view. On the lateral image intensifier view, this needle should be in line with the target disc space. This helps the surgeon plan the ideal location for the mini-open skin incision.
- For obese patients (BMI over 35), the initial incision should be made more lateral to allow for adequate lateral-to-medial pedicle trajectory.
- AP image intensification is used to check for a narrow posterior pelvic inlet, which may obstruct proper screw trajectory at S1.
- If the inlet is too narrow the iliac crest bone graft may be harvested through the Wiltse-approach skin incision to remove the intervening pelvic bone prior to placement of tubular retractor.
- The surgeon should look for the Wiltse intermuscular plane after making the skin and fascial incisions.
- Take the time to identify initial landmarks with image intensification before bone decompression or instrumentation. Due to limited visualization provided by tubular retractors, the lamina may be mistaken for the transverse process, leading to attempted placement of the pedicle screw at the lamina/spinous process junction instead of at the transverse process/facet junction. Image intensification helps minimize such errors.
- The pedicle entry points are prepared with drill and gearshift. Pedicle markers are placed prior to performing a facetectomy for a TLIF. The pedicle markers serve as an orienting guide to help the surgeon avoid excess facet removal with resultant pedicle violation.
- Time must be taken to fully remove the disc material and care taken not to violate the bone endplates during interbody preparation in order to avoid cage subsidence.
- Trials may be used to dilate the interbody space to restore foraminal height bilaterally and to restore lordosis. This avoids the need to distract the pedicle screws, which may loosen if the patient is osteopenic.
- Iliac crest autograft and local bone autograft should be packed anterior to and within the interbody cage to achieve fusion.
- Compressing the pedicle screws bilaterally without performing bilateral foraminotomies may cause iatrogenic foraminal stenosis.
- We prefer to carry out the TLIF procedure with the patient on a Wilson frame/OSI Jackson table. Initially, the frame is cranked to the kyphotic (up) position to make decompression and graft insertion easier. Prior to securing the rod, the frame is returned to a lordotic (down) position.
- We use EMG screw stimulation to check for pedicle breaches with mini-open TLIFs.
- For percutaneous pedicle screws, stimulus-evoked EMG testing to detect breached pedicles is less reliable. Typically a sheathed tap is stimulated to assess EMG with percutaneous screws.
- References used for this tips and tricks: [12, 17, 23, 25].