Chapter 7
Lateral Lumbar Interbody Fusion

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Indications

Minimally invasive lateral retroperitoneal transpsoas approach for lumbar interbody fusion, or shortly Lateral Lumbar Interbody Fusion (LLIF) is the fastest growing type of minimally invasive spinal fusion in the United States.

The common indications for LLIF include:

- Segmental instability with grade 1 or 2 spondylolisthesis
- Segmental instability after previous laminectomy and/or discectomy
- Severe degenerative disc disease with resultant low back pain, with or without radiculopathy, after failure of conservative treatment
- Severe degenerative disease with latero-listhesis and/or focal scoliosis

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Contraindications

Contraindications for this technique include:

- Grade 3 or 4 spondylolisthesis
- Anterior location of the femoral nerve, as seen on the axial MR images, particularly at the L4–5 level
- Previous retroperitoneal operations resulting in scarring

This technique can be applied in the lumbar spine at L4–5 and above, and in the thoracic spine below T5.

Most of the morbidity of this procedure comes from the transpsoas approach. Two conceptually different LLIF psoas dissection techniques can be used. One involves reliance on EMG and X-rays for correct placement of the tubular retractor, whereas the other relies on X-rays for the placement of an initial outer retractor on the surface of the psoas, followed by dissection of the psoas under direct visualization for placement of the second inner retractor. Once the lateral aspect of the annulus fibrosus is exposed, the discectomy and interbody cage placement is similar with both techniques.

Preoperative Planning

Common imaging modalities used preoperatively include MRI, dynamic X-rays, and CT scan.

The MRI is the most important preoperative study. Sagittal images provide information on the disc height, dimensions of the spinal canal and degree of stenosis, and status of the posterior elements. Axial images show the position of the femoral nerve in relation to the lateral aspect of the disc, the position of the large vessels, and the presence of possible retroperitoneal scarring.

The lateral X-rays show the height of the iliac crest in report to the L4–5 disc and should be done in all cases anticipating an L4–5 fusion. If the iliac crests projection, on a true lateral image, is above the midbody of L4, we recommend using an alternative approach (ALIF or MI TLIF), since the lateral approach, even with angled instruments, will be very difficult. The flexion-extension imaging shows possible dynamic instability. Standing scoliosis films may be necessary if deformity is suspected.

The CT scan may provide additional information on the bony anatomy (endplate changes, osteophytes, previous laminectomy, pedicle size etc), but is not mandatory for the preoperative work-up in most cases.

A DEXA scan can be done in patients suspected to have osteoporosis.

Surgical Technique

The following operative steps are described:

– patient positioning
– skin incision and bone marrow aspiration

– psoas dissection, EMG based
– psoas dissection under direct visualization
– discectomy
– cage insertion
– lateral plating
– closure
– patient repositioning
– percutaneous pedicle screw insertion

Patient Positioning

Correct patient positioning is critical, particularly in obese individuals. The patient is initially placed supine on the operating table for endotracheal intubation. A draw sheet under the patient is used to roll him 90°, in lateral decubitus position, usually with the left side up (due to the advantageous position of the great vessels when approaching from the left). A beanbag is NOT used for stabilization, as it may interfere with the lateral fluoroscopy. The back of the patient should be positioned at about 5 in. from the edge of the table, so that the table rail does not overlap with the lumbar spine on lateral fluoroscopy. A chest roll is placed in the patient's axilla. Patient's head is brought back towards the edge of the table, and the anesthesiologist typically inserts 2 or 3 folded sheets under the patients' head to keep it level with the rest of the body. Patient's arms are folded at the elbows; a folded pillow is placed between the bed and the lower hand, and another folded pillow is placed between patient's forearms, with the endotracheal tube fitting in the fold of the pillow. This position is maintained with tape starting anteriorly at the corner of the table and rolling over the patients forearm and shoulder to the other side of the table. Once the head and arms are in proper position, attention is turned towards immobilizing the thorax and pelvis in adequate position. The natural tendency is for the thorax to roll forward; therefore, with the assistant maintaining the thorax and hips in true lateral position, several rolls of tape are used to stabilize the patient to the table at the levels of the hip as well as upper thorax. We start with 3-in. silk tape at the edge of the table, on the rail anterior to the hips, go on the hips right below the iliac crest (without any protective towels!), then continue to the posterior rail, go under the table, and then continue one more time over the hips and to the posterior table rail. The same process is repeated at the thorax level, this time protecting the nipple. A final taping in a "figure-of-8" can be done, starting longitudinally at the level of the left hip, go caudally along the left thigh (protecting the fibular notch to prevent a peroneal injury), go to the anterior rail, under the table, and posterior rail, then along the calf in a caudal-cranial direction, and ending at the anterior rail (Fig. 7.1). This final taping also helps in obese patients by placing some tension on the lateral flank skin and making the incision easier.

The patient's hip joint should be placed at the level where the table can be flexed, in case further exposure of the L4–5 level is needed. Patient's legs are placed in slight flexion with a pillow in between the knees.

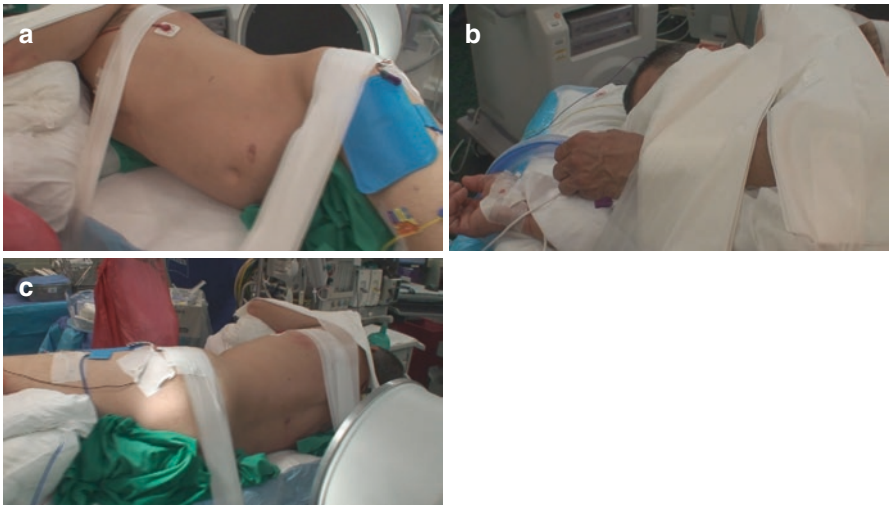

Fig. 7.1 Patient positioning. (**a**) and (**b**) Anterior view: the arms are flexed with pillows under and in between them. (**c**) Posterior view: the chest and hips are double-taped to the table

The first fluoroscopic image to be obtained is the AP. The table, not the C-arm, is tilted until the spinous process of the level of interest is exactly in the midline between the two corresponding pedicles. The C-arm is then switched to the lateral position, and the bed usually has to be placed in slight Trendelenburg position in order to achieve a true lateral image, with the two pedicles of the level of interest overlapping perfectly and each endplate appearing as a single line.

Skin Incision and Bone Marrow Aspiration

After this, the projection of the disc of interest is marked on the skin as guided by the lateral fluoroscopic image. This is typically just above the iliac crest for the L3–4 disc, and at the level of the crest for L4–5. Of course, if the L4–5 projection is below the crest, the skin incision should still be made at the top of the crest.

The skin incision follows the skin mark as described above and is typically about 3 cm in length. After local coagulation, the incision is extended through the superficial fascia, but not deeper.

We prefer to aspirate bone marrow from the anterior iliac crest at this time. From the anterior corner of the skin incision, the fascia is followed caudally to its' insertion on the iliac crest. The Jamshidi needle is then inserted into the crest as anterior as possible, where the crest is thicker. If actual cancellous graft is needed, we recommend harvesting it through an anterior, separate skin incision, as the crest is too thin in its' midportion (at the level of our skin incision) to be used for autologous graft harvesting.

Once the fascia is sharply open under the skin incision, the three muscles to be dissected (external oblique, internal oblique, and transversalis) follow three different directions and can be felt with the tip of the finger as the dissection is bluntly performed. Once the transversalis fascia is penetrated, a "pop" sensation is felt and the tip of the finger palpates a loose areolar tissue, which is the retroperitoneal fat. The finger is swiped over posteriorly over the quadratus lumborum muscle, and the retroperitoneal content is moved anteriorly. I prefer to insert two and then three fingers through the lateral abdominal wall opening, in order to make it easier to insert the tubular dilators and retractor. The blunt retroperitoneal dissection is continued until the tip of the finger encounters the psoas muscle. At this time, the tip of the transverse process of the level of interest can also be felt posterior to the psoas muscle. The psoas dissection is then performed differently, depending on the system employed.

Transpsoas Approach, EMG Based

This is the originally described approach and involves placement of a thin probe through the psoas muscle, targeting the junction between the anterior two thirds and the posterior third of the disc projection on lateral X-ray. The thin probe has directional electric conductivity, so that the base of the probe can be connected to a stimulating electrode and EMG recording from specific muscle groups determines the proximity of the motor nerve to the tip of the probe. Recorded values of 10 mA or above are considered safe, whereas values of 3 mA or less suggest direct contact between the tip of the probe and the motor (femoral) nerve. We prefer to place the small probe as far posterior as allowed by neuromonitoring, i.e., until values close to 10 mA are obtained upon stimulation. If this value is achieved while the tip of the probe is still too anterior, then the probe is pulled out of the psoas muscle and reinserted at a more anterior point, but with a more anterior-to-posterior angulation (the idea being to place a few more muscle fascicles between the tip of the probe and the nerve). The femoral nerve originates from the L2, L3, and L4 spinal nerves and is typically located posteriorly, close the neural foramina, but can be occasionally be found as far anterior as the middle of the disc projection, particularly at L4–5.

Once the small probe is placed in the best possible position (as far posterior as possible, while still recording over 10 mA), the C-arm is moved cranially and a Kirschner wire is placed through the probe into the soft disc. The position is verified again with fluoroscopy, to make sure the probe did not slip in a different position (since the disc feels like a hill, more prominent than the vertebral bodies above and below, the probe can easily slip cranially or caudally, particularly during the stimulation, when the contractions tend to move the probe). Sequentially larger diameter dilator tubes are then placed over the initial probe, and then a tubular retractor of appropriate length is sled over the tubes and then locked to the side of the table in the desired position via a rigid arm.

One of the most frustrating situations arises when the second and especially the third dilator yield a response at values less than 10 mA, sometimes as low as 5 mA. In these cases, we pull out the dilators and the pin, and reinsert at a more anterior point, but with a more anterior-to-posterior angulation, and try to start at a higher response with the small probe (e.g., 15 mA), anticipating that this response will get lower as the larger dilators are used. At the extreme, when the re-docking is performed by going anterior to the psoas muscle, this technique becomes the OLIF.

The tubular retractor typically has several parts that can be retracted in order to provide a larger field of view. Once the position of the retractor is confirmed with fluoroscopy and the exposed field is free of motor nerves (as tested by EMG direct stimulation), the retractor blades can be further stabilized either by a shim going into the disc space or by small screws going through the cranial and/or caudal blades and into the vertebral body. At this point the lateral aspect of the annulus fibrosus should be apparent. Sometimes, a small amount of muscle fibers remain between the tip of the retractor and the disc and can be easily dissected away with a Penfield 4 (but NOT with the Bovie cautery). Bleeding from small veins can be controlled with bipolar cautery, if necessary.

Transpsoas Approach Under Direct Visualization

This approach was more recently described and we used it with good results [1]. After the blunt dissection of the lateral wall muscles is completed, a tubular dilator is placed under fluoroscopic guidance targeting the junction between the anterior third and posterior two-thirds of the lateral disc projection. This is in contrast with the EMG technique, which targets a more posterior point. The tubular dilator is also guided with the finger, but its' tip is placed on the surface, and not through, the psoas muscle. A second and third dilators allow for placement of an appropriate length outer retractor that also rests on the surface of the psoas. After lateral fluoroscopy confirmation of adequate position, blunt psoas dissection under direct visualization (operative microscope or loupes) is performed with Penfield 4 and blunt Cobb instruments. Once the disc is encountered, gentle opening of the dissecting tools allow for exposure of the annulus fibrosus and placement of the independent inner retractor blades that will maintain the exposure for the remainder of the case. The inner retractor blades are stabilized either to directly to the table, or via a rigid ring to the outer retractor, which in turn is locked to the side of the table. Final imaging should confirm the adequate placement of the inner retractor blades. This technique has the potential advantage of protecting both motor and sensory nerves, since it does not directly rely on neuromonitoring. If the femoral nerve is encountered in the depth of the exposure, the inner retractor blades are repositioned, if possible (Video 7.1). Alternatively, the inner retractor is removed (or not inserted) and the outer retractor is moved more anteriorly on the surface of the psoas before muscle dissection is performed again.

Discectomy

Regardless of the system used for psoas dissection, once the retractor blades are in place, the lateral aspect of the annulus fibrosus is exposed. (This approach can also be used for removal of a far lateral disc herniation (Video 7.2), but the docking in those cases is obviously further posterior.) The surgeon should now see the highest point of the curve of the lateral aspect of the disc, and typically the discectomy is centered on this point. The annulotomy must be 22 mm in length in order to accommodate the standard size implant. If more space is needed in the exposure, it is usually easiest to continue the dissection anteriorly and place a retractor against the anterior longitudinal ligament (ALL); however, caution must be exercised at the time of implant (or trial) insertion, so that this doesn't slip anterior to the ALL into the great vessels. The location of the annulotomy (central versus more anterior) is very important, since the trials and eventually the cage will follow the space created by the annulotomy and discectomy.

Once the 22 mm annulotomy is performed, the disc material is removed with a combination of Cobb dissectors, rasps, and curettes. We prefer not to use disc shavers, since they can damage the endplates by creating a circular rather than square discectomy. Sometimes, the disc space is so narrow that it can only be accessed, initially, with a blunt Cobb; once the disc direction is established, rasps and sharp Cobb dissectors can complete the discectomy subsequently. We insert several trials of increasing height, pushing the dislodged disc material towards the bottom part of the disc, which facilitates its' removal with pituitary rongeurs (if not removed, this disc material will prevent the trial and/or cage from being inserted all the way to the other edge of the disc). Once most of the disc material is removed, the contralateral annulus is penetrated with a sharp Cobb under live AP fluoroscopic guidance; the tip of the Cobb has to go about 1 cm past the edge of the vertebral body.

Cage Insertion

The height and length of the interbody implant can be determined based on trials. We prefer to trial to a slightly less height than the cage (e.g., we trial to 11 mm height when planning to insert a 12 mm-height cage). We also prefer to insert the cage in between two "sliding" blades, in order to protect the endplates as well as keep the graft inside the cage.

Regarding cage insertion, several characteristics are important.

- Height. We prefer to use implants (filled with autologous bone or fusion extenders) with the height 2–3 mm larger than the original disc height; this allows for indirect decompression of the canal and posterior elements, without predisposing the construct to subsidence.
- Length. The choice of implant length depends on multiple factors, but we typically use implants that are contained within the disc space and not overhanging

on both sides, as some surgeons prefer. It has been shown that fusion rates correlate with the width, rather than the length, of the cage.
- Width. We use almost exclusively 22 mm-wide cages, with the 19 mm-wide cages reserved for the rare cases in which the femoral nerve is in the way or the anatomy is not favorable (Video 7.2). We have not used 26 mm-wide cages, but these may be appropriate for large-size individuals.
- Position. It is important to remember that the position of the cage in the disc space is determined at the time we make the annulotomy. Once the annulotomy and discectomy/endplate preparation are complete, the cage will follow the space created and cannot be adjusted to a more anterior or posterior position. Most cages are inserted around the center of the disc (the "50 yard line") or slightly anterior to it. This allows for good foraminal (indirect) decompression and some restoration of lordosis. However, if restoration of lordosis is the primary goal, we place the cage as anterior as possible (without disrupting the ALL) and later compress on the pedicle screws. We have not performed ALL release (which would enhance the achieved lordosis even further) since the risks of this maneuver have not been fully established.
- Dynamic (expandable) cages. The advantage of expandable cages is obvious—ease of insertion and ease of lordosis restoration (as much as the anterior longitudinal ligament permits). The downside is that, once the cage is expanded, the graft material may become loose and, according to Wolff's law, fusion rates may decrease. Therefore, in these cases, we recommend inserting more graft, preferably through the cage, after expansion (aka "backfill" of the cage).

After cage insertion, hemostasis can be achieved with Gelfoam and/or Surgiflo. Before removing the retractor, we always check to make sure the bottom of the cage is below the edge of the disc and the hemostasis is pristine. Final AP and lateral images are obtained to confirm the correct position and copious irrigation with antibiotic solution is performed.

Lateral Plating

We occasionally use lateral plating (as opposed to percutaneous pedicle screws) in patients with collapsed disc space and low degree of instability. Placement of a lateral plate requires slightly more cranio-caudal exposure, which may be difficult at L4–5. Moreover, we always use 4-screw plates, since the 2-screw plates are biomechanically insufficient. Some systems allow the plate to be slid over a temporary pin attached to the center of the cage, thus facilitating alignment of the cage and plate. Before inserting any of the screws, we take a lateral image to make sure the plate is long enough and is in roughly adequate position. Then, we start with the anterior and caudal screw. A pilot hole is made with the high-speed drill, followed by an awl inserted at a slight anterior to posterior angle, followed by the screw; we try to stay parallel to the endplate when inserting the screw. We do not currently use a bicortical purchase, unless the patient is osteoporotic. The screw is left slightly

proud, to allow for some mobility of the plate until the second screw is inserted. After one more lateral image confirmation, we insert the anterior and cranial screw, using the same technique. Finally, the posterior cranial and caudal screws are inserted straight down (with no anterior to posterior angulation) and all the screws are tightened down. Plating can be difficult at L4–5, when the caudal screws may have to angled caudally (because of the iliac crest height), and also in patients with large lateral osteophytes, in which the plate cannot be brought all the way down to the vertebral body unless the osteophytes are partially removed prior to plate placement.

Closure

The muscles revert to their initial position and we only close the fascia with 0 Vycril on a UR needle, followed by the skin (interrupted 3-0 Vycril for the hypodermis and 4-0 running Monocryl for the subcuticular layer).

Patient Repositioning

We use bilateral percutaneous pedicle screws in most cases. Some surgeons insert them in lateral decubitus position, in order to save time. We prefer re-positioning the patient in prone position. Thus, the stretcher is brought to the beside behind the patient, the tape is released at all levels, and the patient is allowed to roll back on the side of the OR table and then slid onto the stretcher. The OR table is cleaned and two chest rolls are placed on it, covered by a draw sheet. The patient is then rolled onto the OR table in prone position.

Percutaneous Pedicle Screws

The patient is placed in prone position with the arms tucked to the sides and with adequate padding for all pressure points.

The accurate placement of the pedicle screws is dependent of the quality of the radiologic images. Therefore, obtaining true AP and lateral images prior to skin incision is of utmost importance.

The AP image should be obtained first. The C-arm is locked at 90°, perfectly centered on the vertebral body of interest. This is particularly important if the patient has significant deformity, in which case the C-arm should be readjusted for each vertebral body. The spinous process of the vertebral body of interest should be centered between the two pedicle rings; otherwise, the table (NOT the C-arm) should be tilted left or right until the desired position is achieved. Then, the table is placed

either in Trendelenburg or reverse Trendelenburg until the superior endplate of the vertebral body of interest becomes a single line.

The lateral image is obtained next. If the AP image was perfect, now the posterior margin of the targeted vertebral body should appear as a single line. The perfect lateral image is obtained by "wagging" the C-arm until the two pedicles of the vertebral body of interest overlap. At this point, the superior and inferior endplates should also appear as a single line.

After this, the bony landmarks can be marked on patient's skin under AP fluoroscopy: the midline, the left and right pedicle lines, and the interpedicular line for the vertebral body of interest. The skin incision should be about 2 cm in length, vertical and centered on the interpedicular line, about 4–6 cm off the midline. This point is typically at or just lateral to the tip of the transverse process on the AP image. In large patients, the skin incision has to be made further lateral, in order to maintain the same lateral-to-medial angle of insertion.

The lumbar fascia is then incised with the knife medial to the skin incision. It is important to remember that the fascia is the layer that limits the exploration of the deep bony landmarks. Continuing in the same lateral to medial direction, the index finger can be inserted to find the junction between the transverse process and the lateral facet. Typically, the lateral facet is first encountered (since it is the most superficial), and then the finger is allowed to slide lateral to it and land on the posterior aspect of the transverse process. If the incision is too small to accommodate a finger, the same landmarks can be identified with the tip of a Jamshidi needle, with the aid of frequent fluoroscopic images. The ideal docking point is at the junction of the transverse process with the lateral facet, as medial as allowed by the lateral facet. On the AP image, this point will appear just outside the pedicle ring; if it appears inside the pedicle ring, it is likely that the tip of the needle is actually riding high on the lateral facet, not on the transverse process. On the lateral image, the tip of the needle should be just above the ring of the transverse process, not high on the lateral facet, and the trajectory should pass through the pedicle, parallel to the endplates. If fine adjustments are necessary, the tip of the Jamshidi needle can be moved with both hands (for maximal control) in millimeter increments, on the base of the transverse process, until the desired position is achieved.

Once the correct docking point is obtained, the needle is gently tapped through the pedicle. For the lower lumbar pedicles, the direction is typically lateral to medial and cranial to caudal, but the angles vary with each level. As the needle is advanced through the pedicle, there should be no increased resistance (that would signify cortical bone and therefore imminent pedicle wall breach). The most important images are obtained when the tip of the needle reaches the base of the pedicle on the lateral image; at this time, the tip of the needle should be still within the pedicle ring on the AP image.

At this time, neuromonitoring is usually employed. The shaft of the needle is stimulated, and a response of 10 mA or above signifies that the medial or inferior pedicle walls have not been breached.

A particular situation is encountered if the tip of the needle is very close to the medial border of the pedicle ring on the AP image, and neuromonitoring yields low

responses (e.g., 4–7 mA). In this situation, it is likely that the needle has violated the lateral recess, which sometimes loops under the line of the pedicle ring. Therefore, it is recommended that the tip of the needle should be well within the pedicle ring on the AP images, when it reaches the base of the pedicle on the lateral images.

Another important technical tool is changing the direction of the Jamshidi needle while in the pedicle. Indeed, if the original trajectory is angled too much lateral to medial, and the tip of the needle gets too close to the medial border of the pedicle on the AP image, the angulation of the needle can be changed to a more straight trajectory, without withdrawing the needle from the pedicle. The angulation can also be changed in a cranio-caudal direction, in order to keep the needle parallel to the endplates. Beveled needles are particularly useful in this situation.

Once the needle trajectory is deemed safe, the tip of the needle is advanced into the vertebral body for a couple of centimeters, and then the center part of the needle is removed and a K-wire is inserted for about another centimeter past the tip of the Jamshidi needle, in order to stabilize it to the cancellous bone and make it less likely to inadvertently come out during the placement of the tap and screw. Then, the Jamshidi needle is removed, while the K-wire is kept in place with the other hand.

After this, most systems have a series of tubular dilators that slide over the K-wire; the outer dilator and the K-wire are kept in place, whereas the inner dilators are removed to make room for the tap and screw. The tap is then advanced over the K-wire into the pedicle of the vertebral body; it is sufficient (and recommended) to tap only past the base of the pedicle and not all the way into the vertebral body. For biomechanical reasons, we recommend undertapping by 2 mm (i.e., use a 4.5 mm tap for a 6.5 mm screw), in order to maintain the good purchase of the screw into the bone. It is important to maintain the direction of the K-wire with the tap; if the tap is not aligned with the K-wire, the part of the K-wire in the vertebral body starts to bend at the tip of the tap, and when a critical angle is reached, the tap cannot advance any more, and any further turns of the tap do nothing but strip (and destroy) the pedicle.

The tap is then removed and the screw (typically 6.5 × 45 mm for the average person) is inserted over the K-wire. Once the tip of the screw passes the base of the pedicle, the K-wire can be removed, and the screw further inserted through the previously created trajectory. The screw insertion must stop just before the head of the screw abuts the lateral facet; otherwise, the screw head loses its' poliaxial capabilities and makes subsequent rod insertion more difficult. All the screws have extender blades attached to their heads, in order to facilitate rod placement.

Of course, at least 2 pedicle screws per side have to be inserted. The described technique is changed in the fact that most surgeons choose to insert all the K-wires in their respective pedicles before performing the tapping and screw insertion. In patients requiring long constructs (e.g., for trauma fixation, or in deformity correction), it is extremely important to be consistent with the docking point for each level, since the junctions between the transverse process and the lateral facet are lined up in a cranio-caudal fashion.

Specific Levels

The L4–5 Level

This level is the most commonly treated as well as the most difficult to treat. Two elements are critical for feasibility: the iliac crest height and the femoral nerve position.

A preoperative true lateral X-ray is mandatory and will show the height of the iliac crest in rapport to the L4–5 disc. If the crest is below the disc, then the surgery can proceed without worries, similar to an L3–4 disc. If the crest projects at the mid-body of L4, several adjustments can be made: the table can be flexed to open the L5–S1 disc and provide a little more exposure for L4–5; the skin incision can be made over the iliac crest edge and the finger dissection of the abdominal wall muscles can be forced right over the bony ridge of the iliac crest; appropriate angled instruments must be used for discectomy and implant insertion. If the crest projects higher than the L4 midbody, then a different approach (e.g., MI TLIF) should be used; however, this usually only happens in patients with transitional anatomy. Another option is to convert to the more anterior approach, i.e. the OLIF.

The femoral nerve position on the side of the disc can be determined on the axial T2-weighted MR images. The nerve appears as a dark shadow surrounded by white fat and is typically located posteriorly, close to the lumbar foramen. However, in about 25% of patients, it can be located as anterior as the middle of the lateral aspect of the disc. These cases should be identified preoperatively and an alternative route (e.g., MI TLIF or OLIF) should be used. Exposure and retraction of the femoral nerve in these cases is NOT recommended. If the nerve is encountered despite careful preoperative planning, an attempt can be made to insert the cage behind the femoral nerve (Video 7.3), although this is a risky and advanced technique.

The L3–4 Level

This is the second-most commonly treated level as well as the easiest to treat. In fact, we recommend starting with this level, when learning the LLIF technique. At this level, neither the iliac crest nor the ribs are in the way (hence no need for angled instruments). Moreover, the psoas muscle is thinner (thus easier to dissect) and the femoral nerve is located posteriorly (thus not endangered during the exposure). The standard technique described above applies to this level.

The L2–3 Level

This level may be difficult because the tip of the eleventh rib may be in the way. However, we recommend NOT removing the rib; sufficient exposure can be achieved going around it. Once the retroperitoneal space is accessed, the rest of the

procedure is relatively easy, as the psoas muscle is thin and the femoral nerve (the L2 component) is not in the way.

The L1–2 Level

This level may be difficult because the surgeon must make the skin incision parallel to the ribs and dissect the intercostal muscles to gain access to the retropleural, not retroperitoneal, space. As the dissection is continued with the index finger between the inner side of the rib and the parietal pleura, eventually the vertebral body covered by the thin psoas muscle is encountered. The dilators and then the retractor are placed against the diaphragm dome, which will push the retroperitoneal content anteriorly. In order to access the L1–2 disc, a small opening in the diaphragm insertion must be made with the long bayoneted knife, and can be closed at the end of the case (although not mandatory). If the intercostal opening is not lined up with the disc, angled instruments must be used occasionally.

Pearls and Pitfalls

LLIF Versus MI TLIF

While the minimally invasive transforaminal lumbar interbody fusion (MI TLIF) is a great technique that can be applied to most patients with degenerative pathology, the LLIF offers certain advantages that make it a favorite in selected patients. We present below a synopsis of the usual patient presentations (assuming that they have already had unsuccessful maximal conservative treatment) and our selection process of LLIF versus MI TLIF.

At L3–4 and above, we prefer using the LLIF, since the MI TLIF is more difficult and dangerous. Even if there is a disc herniation with a free fragment, we perform the LLIF first, then use a minimally invasive retractor to perform a laminectomy and disc fragment removal, followed by pedicle screw insertion through the same incision.

At L4–5, both techniques can be used, and below we present our selection process.

In patients with low-grade spondylolisthesis and preserved disc height, with or without resultant central or lateral recess stenosis, but without a disc herniation/extrusion, we prefer using the LLIF, because it offers superior biomechanical support and fusion surface. If the patient has a large disc herniation/extruded free fragment, we prefer using the MI TLIF, because it offers direct decompression of the nerve by removing the extruded fragment (this fragment cannot be influenced by the ligamentotaxis, which LLIF relies on, in part, for the indirect decompression).

In patients with severe collapse of the disc space, both LLIF and MI TLIF work well and the choice is usually based on other anatomical factors (e.g., the iliac crest height) and surgeons' preference.

In patients with post-laminectomy instability, we prefer using the LLIF, in order to avoid the posterior midline scarring.

In patients with single-level focal scoliosis, we prefer using the LLIF approaching from the convex side; this provides easy access to the disc and excellent correction of the deformity by the simple insertion of the interbody implant.

In patients with multi-level degenerative lumbar scoliosis, we prefer starting with LLIF at all the affected levels (usually 3 or 4) approaching from the concave side (since it requires less abdominal wall and psoas muscle dissection for the multiple levels), followed by percutaneous screw/rod fixation. It is important to remember that the lateral fusion is only FDA approved for one or two levels.

In obese patients with operative pathology, we prefer using the LLIF when possible, since the abdominal fat falls forward in lateral decubitus and the access to the spine is a lot easier than in the MI TLIF approach.

Discectomy and Endplate Preparation

Since the discs have a bi-convex shape (unless severely degenerated, in which case they become flat), endplate preparation must be done respecting its' concave shape. The best preparation, in our opinion, is done with a wide Cobb (20 or 22 mm) that follows the dissection plane between the disc and the endplate. As the Cobb follows the concave surface of the endplate, the direction of the shaft changes from cranially angled (initially) to straight (as the tip of the Cobb passes the midpoint of the disc). If this direction is not changed, there is a risk of endplate and vertebral body violation in the deep (contralateral) half of the vertebral body.

Stand-Alone LLIF

Most patients undergoing LLIF should have some type of posterior stabilization. The preferred method of most surgeons is the percutaneous pedicle screw/rod fixation, whether unilateral or bilateral. Others have used facet screws or facet dowels.

In selected patients, stand-alone LLIF can also be used. The typical candidate cannot tolerate long operations, but has reasonably good quality bone (i.e., is not severely osteoporotic), no spondylolisthesis, and a collapsed (and sometimes sclerotic) disc space. In these cases, we insert slightly longer cages, extending 1–2 mm beyond the edges of the vertebral body, and we keep the patient in a TLSO brace for 3 months postoperatively.

Spondylolisthesis

These cases are more difficult because there is less disc available for annulotomy and cage insertion, particularly for grade 2 spondylolisthesis (grade 3 and 4 are contraindications, for the same reason). Occasionally, we use 19 mm-width cages in these cases. Once the cage is inserted, particularly if the disc was collapsed, the spondylolisthesis is already partially reduced. The case is finished by using the percutaneous pedicle screw reduction system to complete the realignment.

Previous Discectomy

These cases can be done with no changes from the standard technique, since no scar is encountered during the exposure. One potential concern, particularly in patients who had the discectomy recently, is for the graft to extrude through the posterior annular defect into the spinal canal. However, since the graft is only placed inside the cage and not in front of it, this risk is fairly small.

Previous TLIF

These cases can also be done with no changes from the standard technique, until the time of discectomy. Since the TLIF cage is likely loose (since the re-intervention is done for pseudarthrosis), the surgeon can attempt to remove it in one piece with dedicated instruments (Fig. 7.2). If this is not possible, we have used the high-speed drill or osteotomes to break the cage and remove it in several pieces with the pituitary rongeurs. The rest of the case (discectomy, endplate preparation, LLIF cage insertion) is performed using the normal technique.

Collapsed Disc

When the disc is almost completely collapsed, or when there is a shell of calcification or cortical bone covering the annulus, it may be difficult to access the disc. In these cases, we use the high-speed drill to uncover the “entrance” into the disc, over a distance of 22 mm, sufficient to permit the insertion of a blunt Cobb. Care must be exercised not to go to deep with the Cobb from the first pass, as it may be difficult to pull out. Therefore, we insert the Cobb about a third of the disc at the time, then pull out and reinsert deeper, until the other side of the disc is reached.

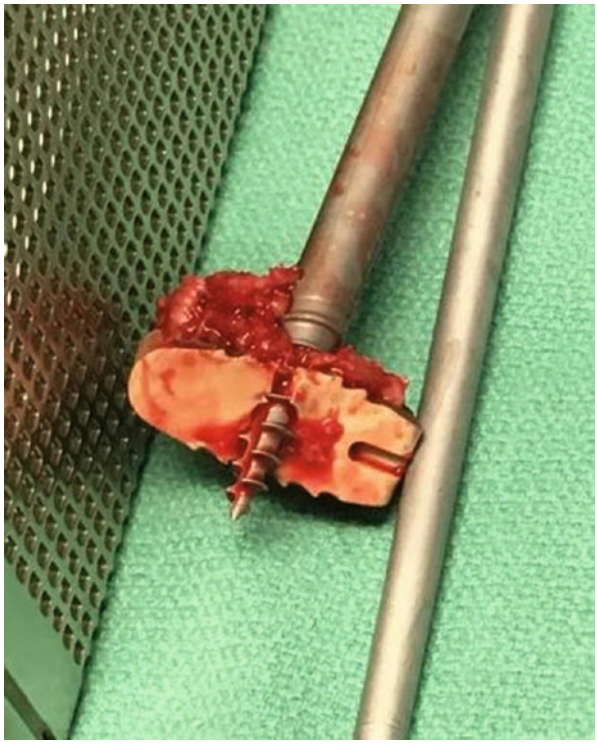

Fig. 7.2 TLIF cage removed via the lateral approach, still attached to the remover

Normal Height Disc

These are typically patients with bilateral pars defects and grade 1 or 2 spondylolisthesis, but with preserved disc height and often with large disc herniations. In these cases, we try to insert 22 mm-width cages (rather than 19 mm) to maximize the fusion surface (since we are asking the bone to grow over a longer distance, between the endplates). Also, since there are bilateral pars defects, it is easy to overdistract; therefore, we insert the cage that feels slightly snug (usually 14 or 15 mm in height) and then compress on the percutaneous pedicle screws in the second part of the procedure.

Penetration of Contralateral Annulus

When the tip of the Cobb reaches the contralateral annulus, it usually has a bouncy feel, unless the disc is severely collapsed and degenerated. In order to penetrate the annulus without going too far into the contralateral psoas, we recommend holding the Cobb from the shaft, just above the retractor, and apply low-force taps until the tip of the Cobb goes through.

The other concern when penetrating the annulus is injury to the contralateral femoral nerve. This occurs if the trajectory of the discectomy is oblique from anterior to posterior, whether planned or accidental. Perfect positioning and frequent lateral fluoroscopic imaging can prevent this complication.

Two-Level LLIF

Most commonly, this is done at L3–4 and L4–5. In these cases, the lateral abdominal wall can be either opened over a wider distance (similar to the exposure for a corpectomy) or two separate entries through the lateral wall can be made. It is a mistake to try to make a single small lateral wall opening in between the two discs and then try to forcefully mobilize the retractor from one disc to the other, as the lateral wall is rigid and the retractor will end up in an angled position at both discs, making the discectomy and cage insertion more difficult than it needs to be.

Multi-Level LLIF

Most commonly, this is done between L1 and L5 in patients with deformity (i.e., scoliosis). This application is not FDA approved, since the lateral fusion is only indicated for one or two levels. We prefer performing the approach on the concave side, since not only the skin incision is smaller (as all the disc lines converge around the same spot on the lateral abdominal wall) but also the L4–5 and sometimes L3–4 discs cannot be accessed from the convex side. The psoas dissection is also limited on the concave side, as the vertebral bodies are collapsed on the concave side of the deformity. Finally, we perform the LLIFs from cranial to caudal, since the insertion of the cage reduces the deformity and, if we started at the caudal level, the cranial levels would become inaccessible through the same skin incision. The insertion of the LLIF cages already partially corrects the scoliosis; the percutaneous pedicles screws and rods complete the deformity correction. This indication is not FDA approved for the lateral approach.

Femoral Nerve in the Way

If the preoperative MRI was adequately interpreted, the femoral nerve should not be encountered in an anterior position. However, occasionally, the MRI can be misinterpreted, and a small amount of what appears to be just fat (white on the T2-weighted images) and with no grey structure to suggest the femoral nerve in it, may actually harbor the nerve. In these cases, we recommend trying to find a window for the annulotomy and discectomy in front or, more rarely, behind the nerve (Video 7.2). If this is not feasible, we recommend aborting the case and using an alternate route to perform the fusion.

Anterior Longitudinal Ligament Release

We have not performed ALL release yet, since the safety of this procedure has not been established. Nonetheless, some surgeons use the ALL release and hyperlordotic cages to increase the length of the anterior column and correct kyphosis or insufficient lordosis. These cages come with a stabilization screw, which prevents them to slip anteriorly and damage the great vessels. Posterior instrumentation is mandatory.

Complications

Nerve Injury

There are several nerves at risk during this procedure and the subsequent pain syndromes have been well described.

In the lateral abdominal wall, the ilioinguinal and iliohypogastric nerves travel in between the oblique muscles. Therefore, dissection of these muscles must be done bluntly, rather than with the knife or Bovie cautery.

On the anterior aspect of the quadratus lumborum and towards the pelvic ring, the lateral femoral cutaneous nerve can be injured during the retroperitoneal dissection. Since this is typically done with the index finger, the surgeon should avoid breaking any "stringy" structure that may be a nerve.

The genitofemoral nerve surfaces on the psoas muscle at the L3–4 level and has a variable position at the L4–5 level. This is the nerve best protected by the direct visualization technique, since it is a sensory nerve and is not detectable by neuromonitoring. It has been our experience that the genitofemoral nerve is often in the way of the transpsoas exposure (Videos 7.4 and 7.5) and, if not visualized (as in the EMG-based technique), can likely be injured.

The femoral nerve is the most important and its injury results not only in sensory, but also motor deficits. This nerve can be injured both directly and indirectly, by stretching it over a long period of time with either the posterior retractor blade and/or by breaking the table too much and putting the psoas muscle and femoral nerve under tension. Neurostimulation at the time of retractor insertion as well as continuous EMG monitoring are used to detect and decrease the injury to this nerve.

Cage Retropulsion

This complication is rare and involves delayed migration of a cage laterally, along its' insertion path. In these cases, if symptomatic, the cage can be re-exposed and either removed or reinserted, this time preferably replaced with an expandable version and/or blocked with a lateral plate.

Subsidence and Vertebral Body Fractures

This is probably an under-reported complication. In patients with osteoporosis, we recommend using the widest cage possible and supplement with bilateral pedicle screws. If symptomatic subsidence or vertebral body fractures occur, posterior instrumentation over one or several segments is usually indicated [2].

Massive Bleeding

This is a rare, but potentially devastating, complication [3]. If injury of the great vessels occurs, we recommend temporary tamponade and emergent consultation of the vascular or general surgeon. Occasionally, the vascular injury can be repaired by endovascular stenting, rather than open repair or ligation.

Pseudarthrosis

With proper technique, very few patients should experience this complication. The treatment consists in adding a postero-lateral and posterior fusion, possibly adding (off-label) rhBMP.

Adjacent Level Disease

This is a delayed complication that typically occurs 5–10 years after the original surgery. If the L5–S1 level is involved, we recommend revising with a stand-alone ALIF, unless contraindicated. If L3–4 of above levels are involved, we recommend using additional LLIF cages.

Literature Review

This technique has been extensively covered in the recent years' literature.

Initial studies focused on the feasibility of this approach and the range of complications [4–10]. Davis et al. found that the proximity of the neural elements to the L4–5 disc space will almost always lead to their displacement during the procedure [5] and Banagan et al. showed that there is no absolute safe zone when performing the procedure from L1–L5 [6].

Subsequent studies evaluated the specific complication profile [1, 11, 12] and the long-term results [13–17] of this approach. Youssef et al. found a low complication

rate and high arthrodesis rate in a retrospective chart review [7]. A retrospective review by Cahill et al. also showed a low complication rate, with a 4.8% rate of femoral nerve injury at L4–5 and 0% at higher levels. However, Joseph et al. performed a meta analysis that showed a 9.4% rate of transient motor deficit, 2.5% permanent motor deficit and a 27.1% rate of sensory deficits [18]. In comparison to the ALIF, a meta-analysis by Hartl et al. found a higher rate of neurologic complications (but lower overall complication rate) due to lumbar plexus injuries [19].

Recent literature has focused on the expansion of indications for this technique [20, 21] and further refinement of outcomes [22–24]. It has utility in trauma, osteodiscitis and deformity surgery (with correction of upwards of 20° of coronal curvature reported in the literature) [25]. Long-term outcomes are generally good, with fusion rates approaching 90%.

Conclusion

The LLIF is an excellent option for selected patients and should be included in the armamentarium of every spine surgeon.

Addendum: Informative Letter to the Patients

The following informative letter is NOT intended to cover ALL the possible complications and scenarios. It is only intended to serve as a general guide, to improve patients' understanding of the operation.

This procedure can be very long. Despite careful padding of all pressure points, abrasions and pressure sores can occur. Generally these are minor, but can be serious, especially if they occur on the face. Nerve damage, particularly at the joints, can also occur. Blood clots forming in the legs, with potential death from spread to the lungs, are always a worry, and we use special inflatable devices to minimize that risk. Blood loss during this kind of surgery is normal and unavoidable, and sometimes we need to give transfusions from the blood bank. All of the blood is carefully tested, but unfortunately no test is perfect and there is always a small risk of acquiring some disease, such as hepatitis or AIDS. Death from anesthesia reaction or massive blood loss is possible, but fortunately extremely rare.

We make a one-inch skin incision on the side, just above the hip bone, usually on the left. Before we go through the abdominal wall, we use this incision to take a small amount of your bone marrow from the hip bone, to concentrate it and use it for the fusion. Rarely, you may experience pain and soreness at the site where bone marrow has been harvested. Damage to small nerves in the area can lead to numbness or even pain towards the thigh or groin area.

We then dissect the muscles in the abdominal wall to get to the abdominal cavity. Sometimes, this may cause pain and/or numbness in the groin or anterior thigh.

Using our fingers, we then sweep the bowels and abdominal organs out of the way and reach the spinal column with a small retractor, under X-ray guidance. At this point, an operating microscope is used to allow us to keep the incision as small as possible, yet have excellent vision so we can see what needs to be done. In order to get to the spine, we have to go through a thick muscle called psoas. There are several nerves in this muscle. We try to protect these nerves by doing the dissection under direct visualization and also by recording any abnormal electric potentials that appear when the nerves are stimulated. Nonetheless, it is very common in the first 3 months after surgery to have pain and/or paresthesias over the thigh or groin. Sometimes, when the larger nerves are stretched or damaged, you may have weakness in the leg, especially when trying to straighten out your knee. While most of these changes resolve by 3 months after the surgery, sometimes they persist forever. Another potential complication (but fortunately very rare) is injury to the bowels, kidney, or large vessels; these may require opening the abdomen widely (usually by a general surgeon) and may result in serious damage and even death.

Once we get to the side of the spine, we then remove the bad disc or discs and prepare the area to accept the fusion construct. After we take out the disc, we replace it with a synthetic box we call "cage" that is filled up with bone graft and will promote the bony fusion. We are careful to avoid damage to the nerves in the spinal canal, which are very close to our "working area". However, such damage (while very rare) is a risk and can result in paralysis from nerve damage, loss of bowel, bladder, and sexual function, numbness, lack of feeling or sensation, or even severe pain below the waist. X-rays are used throughout the procedure to maximize the safety.

In order to give instant strength and stability to the spine and to increase the probability of the natural bony fusion healing properly, we use either a lateral plate (that can be inserted through the same incision) or screws and rods (that have to be inserted through two 1-in. incisions in the back). We place the screws accurately with the aid of intraoperative X-ray guidance. Nerve or blood vessel damage is possible, but fortunately quite rare. These devices function as an internal cast to keep the spinal bones immobile while the bone cells are forming the fusion mass. (If you're gluing two pieces of wood together, the glue is more likely to stick if you keep the wood pieces in a vice until the glue is set.) The screws and rods have been engineered and designed for endurance, but if a natural bony fusion does not form, eventually they will work loose or break. Another risk of any type of implanted foreign (non-natural) body is the possibility of infection. If this occurs (which is rare) it is early, and not months or years later. Generally removal of the screws is not necessary (to treat the infection), but prolonged antibiotics and debriding (cleaning up) procedures could be required.

It is important that you understand that this is a serious and possibly painful operation with a long and slow recovery. Most frequently, after the surgery you will be moved from the recovery room to a normal hospital room. Occasionally, if the surgery takes longer than a few hours, you may need to be monitored in the intensive care unit. Sometimes the intestines are sluggish for a few days and until you begin to "pass gas", your intake of food may be restricted. We encourage you

to walk with assistance as soon as possible, and it is hoped that the total hospital stay will be in the range of 1–4 days. Of course, this is varied as needed on an individual basis.

At home we would encourage a program of walking on a level surface, gradually increasing the distance to between 2 and 3 miles a day. At about 3 months, a home exercise regimen can be cautiously started. Return to daily activities is highly variable, but in general it is sometimes possible to return to the equivalent of a light office type job at about that time (3 months). Maximal medical improvement is generally reached around a year after the date of surgery. It is generally not possible to engage in heavy manual labor type occupations following an operation of this nature.

Over the 6–12 months after surgery, it is hoped that the operated discs will heal and grow into a strong bony mass, so as to cause a solid union between the bones. This is a gradual process and at first there is no increased strength. This healing process is dependent upon the patient's powers of healing and does not always occur properly. The use of nicotine in any form (cigarettes, smokeless tobacco, nicotine patches, or nicotine gum) interferes with bone healing and dramatically decreases the odds of a successful fusion. You should not smoke or use nicotine in any form! Generally about 3 months is required for the fusion to begin to set, but strengthening continues for about a year or more. Also, for the first several months after surgery it is best to avoid non-steroidal anti-inflammatory drugs (such as aspirin, Motrin, Aleve, Naprosyn, etc.). These medications may interfere with bone healing. Tylenol use is OK, but you should be careful not to exceed the recommended dose. We expect to achieve a successful fusion for one disc level in about 90% and for two levels in about 80%. Sometimes postoperative X-rays show that the fusion has not healed to form solid bone. Most of the time, this does not seem to matter because a tough scar tissue-like gristle has formed instead and there are no symptoms. Occasionally, however, the failed fusion is symptomatic. That is called a pseudoarthrosis and repeat surgery is sometimes required. The type of surgery in those cases depends on individual circumstances.

Major complications (life threatening) may occur in about 2% of cases. The most common major complication is implant malposition or migration and may require reoperation. Sudden massive blood loss could occur, resulting in death. Other major complications include pneumonia and pulmonary embolism (blood clot going to the lungs).

There is also the chance that another type of fusion operation will be required if this one does not heal solidly. For example, it might be necessary to perform an additional operation in the back or front of the spine, with more bone graft added at that time.

One last potential problem after fusion surgery is what we call "juxtafusional disease". After you have had a successful spinal fusion, that segment becomes immobile and the joints above and/or below that fusion are subjected to increased stress. Over the years, these joints can have problems that may require further surgery.

It is very important to emphasize that no operation or device is a "spine transplant". Results on an individual basis cannot be predicted, and therefore we certainly cannot give any guarantees or promises. Once you have a bad back, you always will have a bad back to some degree. You could be no better, or even worse. Most patients indicate that *on average* the pain is improved from "marked" to "mild". While this is a great improvement, it is usually not improved to "occasional" or "none". Whether you will be able to return to their pre-injury or preoperative level of functioning will have to be determined on an individual basis. As a general rule, it is about a year before patients are "over" the operation because recovery and reconditioning is a slow process. It is sometimes necessary to call upon the Departments of Physical Medicine & Rehabilitation and Occupational Medicine to perform functional capacity evaluations (FCE) to determine a patient's actual limitations and abilities.

My general advice to anyone with a spinal affliction of this nature is to "live with it" (if possible). Of course that's easy for me to say because I'm not the one hurting. This operation has been recommended in the belief that your condition is serious and therefore taking the risks of surgery makes sense. I believe this is a good operation that is the best choice for your particular problem. If your only affliction is pain, the decision is yours and yours alone as to whether you can live with it. While I obviously hope and believe that this operation will help you, I cannot give any guarantees or promises about results. It is possible that you could be the same or even worse. Furthermore, my general recommendation is to "live with it" if possible and avoid the risks and uncertainties of surgery. Nevertheless I am offering my surgical services in an attempt to help you, but the decision to proceed is up to you.

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