CHAPTER 172

Lateral Lumbar Interbody Fusion: Indications and Techniques

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Stabilization and arthrodesis of the lumbar spine may be achieved by various surgical approaches. Traditionally, direct anterior or posterior surgical approaches have been employed that take advantage of natural tissue planes and midline orientation. A lateral approach to the lumbar spine provides a unique surgical corridor to the spinal column but is often avoided due to the risk of nerve injury of exiting lumbar nerves as they traverse the psoas muscle. Though lateral approaches for vertebral corpectomy are sometimes necessary for trauma or tumor, the traditional indications for lateral interbody discectomy and arthrodesis are rare. Recent advances in neuromonitoring and surgical access have enabled lateral lumbar interbody fusion (LLIF) to be performed with increasing safety and thus have been reinvigorated over the past decade. Today, LLIF can be performed in both openly and with minimal invasion and can be done at single or multiple levels. As with all surgery, patient selection is of utmost importance for LLIF to be successful, and potential complications and limitations must be recognized.

The traditional lateral approach to the thoracic and lumbar spines was originally developed by Capener for the management of tuberculous spondylitis (Pott's disease) in the 1950s.[1] Through thoracotomy and retroperitoneal approaches, wide exposure of the lateral spinal column could be achieved for debridement and stabilization of the spine. In the 1970s, Larson et al. modified and popularized the lateral extracavitary (LEC) approach to the thoracic and lumbar spines to treat a variety of pathologies, effectively allowing for an entirely posterior approach to reach the anterior and lateral spine.[2] However, aside from major trauma, infection, or tumor cases, which typically required removal of vertebral bodies, these approaches were not popular for interbody discectomy and stabilization. The risk of nerve injury and the extensive disruption of the psoas attachments were perceived as too great for benign conditions such as degenerative disc disease and back pain. Therefore, LLIF was relegated to rare use, namely, for anterior release in deformity/scoliosis cases.

The LLIF approach has gained increasing popularity with the development of minimally invasive surgery (MIS) techniques. Advantages of MIS techniques include smaller incisions, less tissue dissection, improved cosmesis, decreased blood loss, less postoperative pain, and thus, shorter recovery time and hospital stay. The use of an MIS technique in lateral approach allows access to the lumbar spine through the retroperitoneal fat and psoas major muscle via a small incision using a muscle splitting technique. Advances in electromyography (EMG) neuromonitoring have been incorporated into these techniques, which in turn have made them safer. Pioneering work in minimally invasive LLIF is credited to Bergey et al. for describing an endoscopic transpsoas discectomy in 2004[3] and to Ozgur et al. for describing the minimally invasive lateral interbody fusion technique in 2006.[4] The minimally invasive LLIF technique has been trademarked under the proprietary name Extreme Lateral Interbody Fusion (XLIF, NuVasive, San Diego, CA) or Direct Lateral Interbody Fusion (DLIF, Medtronic, Memphis TN), but the procedure can be performed through a variety of tubular retractors outside of these proprietary formats.

In the minimally invasive technique, access to the disc space is achieved through a minimally disruptive lateral, retroperitoneal, transpsoas approach to the spine using neuromonitoring electrodes to identify a safe corridor and expandable tubular retractors for exposure. This chapter reviews the indications, surgical anatomy, techniques, benefits, and potential complications of open and minimally invasive LLIF techniques. A comparison to anterior lumbar interbody fusion (ALIF) and posterior lumbar interbody fusion (PLIF)/transforaminal lumbar interbody fusion (TLIF) techniques is also provided.

Indications and Contraindications

The goals of LLIF are to access the lumbar disc space safely, release the lateral annulus attachments, remove disc material, and place a structural graft. The results should be increased interbody height, restoration of collapse or deformity, and stabilization of interbody motion. LLIF is most suitable for interbody access from L2 to L4 for degenerative disc disease with or without instability, adjacent segmental disease, degenerative spondylolisthesis (grade I or II), and complex degenerative scoliotic deformity. LLIF can be performed at L1-2, but requires either removal of or maneuvering around the descending 12th rib (Fig. 172-1); it also can be performed at L4-5 but with a higher chance of nerve root injury. Also, the positions of the iliac crests determine whether L4-5 can be accessed. LLIF at L5-S1 is generally contraindicated due to obstruction by the iliac wing (Fig. 172-1). Other relative contraindications include grade III or greater

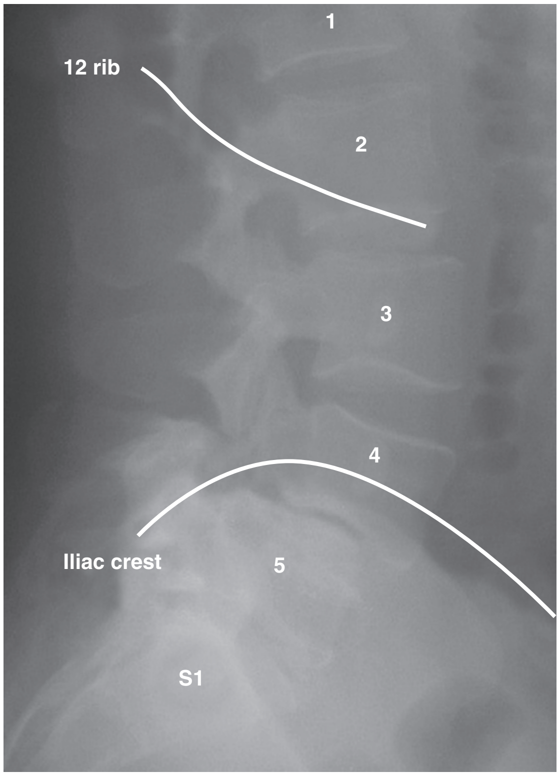


FIGURE 172-1 Lateral lumbar x-ray with an outline of the overlying 12th rib and iliac crest, showing a clear view of the L2-3 and L3-4 disc spaces. Access to the L1-2 and L4-5 spaces would require maneuvering around the overlying bony anatomy.

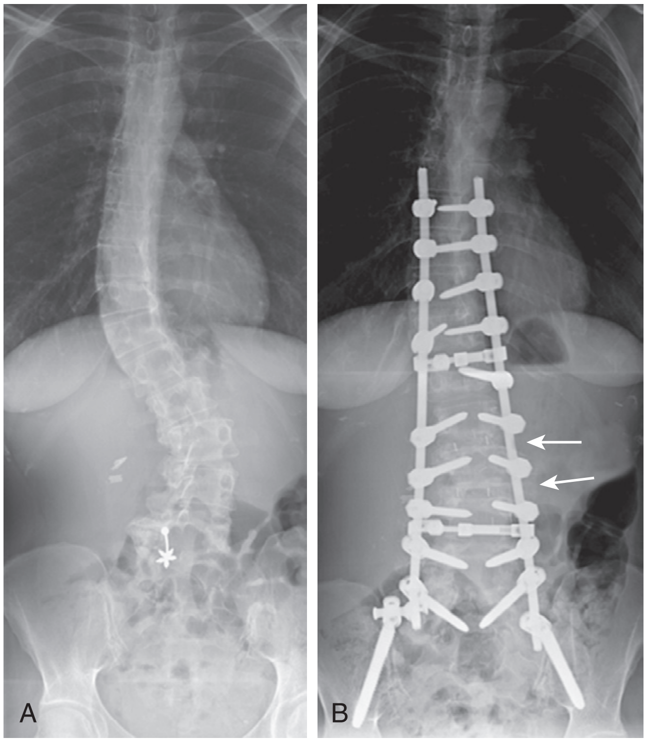


FIGURE 172-2 Degenerative thoracolumbar scoliosis corrected with staged anterior release at L1-2 and L2-3 with lateral lumbar interbody grafting and posterior thoracolumbar–pelvic fixation. A, Preoperative x-ray. B, Postoperative x-ray. Arrows indicate L1-2 and L2-3 interbody PEEK grafts.

degenerative spondylolisthesis, greater than 30-degree lumbar deformities, and bilateral retroperitoneal scarring. In addition, LLIF is generally not used alone when direct posterior decompression is necessary, such as with lumbar stenosis or disc rupture. It can, however, be combined with staged posterior decompression and posterior–lateral fusion if necessary. Patients with radicular symptoms and neuroforaminal stenosis can be considered for indirect decompression by restoring disc height and increasing foraminal diameter via LLIF, which is an active area of investigation.

Clinical Results

Unfortunately, there are limited clinical data concerning outcomes using LLIF techniques (including XLIF, DLIF, or other lateral lumbar interbody approaches). In a prospective series of 100 patients with adjacent segment degeneration after prior lumbar fusion, Rodgers et al. reported an average improvement of the visual analogue score (VAS) for pain from 8.6 to 2.8 within 6 months using the XLIF technique.[5] Though this was not a comparison study, the mere improvement in pain scores in a patient who underwent prior lumbar fusion surgery with a minimally invasive XLIF is clinically meaningful.

LLIF approaches may be especially beneficial in treating certain complex scoliotic deformities, as they provide excellent coronal and sagittal corrective ability (Fig. 172-2). Pimenta et al. reported 23 symptomatic adult scoliosis patients at levels between L2 and L5 using LLIF approaches and achieved significant changes in coronal and sagittal alignment, as well as improved pain score.[6] Benglis et al. also presented favorable short-term outcomes with mid- to high-lumbar coronal deformities treated with LLIF techniques.[7] All patients showed improvement in preoperative pain and solid arthrodesis at 6 months. Similarly, Diaz et al. reported a 3-year follow-up for 39 patients treated with LLIF for symptomatic degenerative scoliosis and showed consistent improvement of the VAS and scoliotic deformity improvement in 3-year follow-up.[8] LLIF can also be combined with other minimally invasive techniques, such as trans–axial lumbar interbody fusion.[9]

Minimally invasive LLIF procedures might be also used for lumbar total disc replacement (TDR). Pimenta et al. described a series of 25 patients who has TDR placed using minimally invasive LLIF for degenerative disc disease with positive discography.[10] The authors reported an improvement of the VAS from 7.5 to 2.6 and Oswestry Disability Index from 60 to 30. They also found this approach to be quick, to have minimal morbidity, and to avoid the need for anterior longitudinal ligament (ALL) removal; therefore, it has at least a theoretical advantage in segmental stability over the anterior approaches. Artificial discs placed in the lateral position have not yet been evaluated or approved by the Food and Drug Administration in the United States.

Surgical Anatomy

As in all surgical disciplines, a thorough understanding of the surgical anatomy involved in LLIF is crucial for maximal patient benefit and complication avoidance. For LLIF,

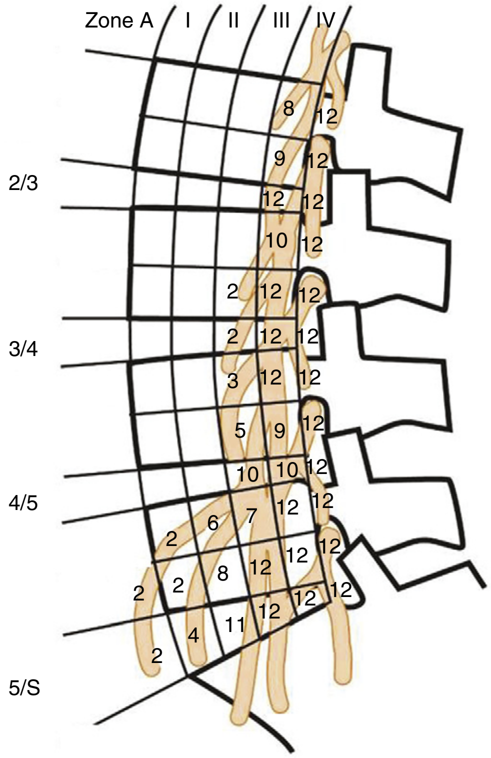


FIGURE 172-3 Branches of the descending lumbar root plexus as they course through the psoas muscle lateral to the vertebral bodies and disc spaces. Lumbar disc levels are labeled to the left. The middle and anterior portions of the disc spaces at L2-3 and L3-4 are generally clear of traversing nerves, while the L5-S1 space is frequently impeded by nerves in the lateral trajectory. The L4-5 space has a variable degree of clearance with respect to traversing nerves and therefore warrants more attention. *(Courtesy of Medtronic, Memphis, TN.)*

the most critical anatomy is the distribution of the lumbar plexus within the psoas muscle, because the approach inevitably requires the use of a dilator or retractors to traverse the psoas muscle, which places the lumbar plexus at risk of injury.

The paired psoas major muscles form a major part of the posterior abdominal wall. They are long, thick, and fusiform shaped, and they lie lateral to the lumbar vertebrae. They arise from the roots of the lumbar transverse processes; pass inferolaterally, deep to the inguinal ligament to reach; and insert into the lesser trochanter of the femur. Another major component of the posterior abdominal wall is the paired quadratus lumborum muscles, which form a thick muscular sheet in the posterior abdominal wall alongside the lumbar vertebral column. They lie posterior and lateral to the origin of the psoas muscle.

The lumbar plexus is embedded mainly in the posterior portion of the psoas, anterior to the lumbar transverse process (Fig. 172-3). It is composed of the ventral rami of the L1 through L4 roots. Major cutaneous branches include (1) the ilioinguinal and iliohypogastric nerves (L1), which supply the skin of the suprapubic and inguinal regions; (2) the genitofemoral nerve (L1 and L2), which supplies the cremaster muscle and the skin over femoral triangle; and (3) the lateral femoral cutaneous nerve (L2 and L3), which supplies the skin on the anterolateral surface of the thigh. The genitofemoral nerve pierces the anterior surface of the psoas muscle and runs inferiorly, deep to the psoas fascia. The two major motor branches of lumbar plexus are the obturator nerve (L2-L4), which emerges from the lower part of the medial border of psoas muscle and supplies the adductor muscles, and the femoral nerve (L2-L4), which emerges from the lower part of the lateral border of psoas muscle and supplies the hip flexors and knee extensors.

In 2003, Moro et al. defined the relationship between the psoas major muscle and the lumbar plexus using cadaveric dissection.[11] Excluding the genitofemoral nerve, the roots and critical branches of the lumbar plexus were found to be overlapping with the dorsal half of the vertebral column above L4-5 in a lateral projection view. The genitofemoral nerve, however, traverses through the psoas to emerge on the ventral surface between the rostral third of the L3 and the L4 vertebral bodies. When genitofemoral nerve is taken into account, only the ventral half of the vertebral column above L2-3 is free of lumbar plexus. The safest corridor, then, for the minimally invasive LLIF approach is the ventral half of the vertebral body above L2-3. Damage to the genitofemoral nerve usually causes only a transient sensory disturbance to the ipsilateral scrotum and medial thigh, which rarely becomes a serious problem. The ventral half of the vertebral column above L4-5 is therefore considered safe if transient genitofemoral nerve dysfunction is acceptable.

In comparison, accessing the lateral vertebral body at or below L5 carries significant risk of damaging critical structures such as the L4 and L5 nerve roots, femoral nerve, and/or obturator nerve. Thus, although there is considerably more space between the psoas major muscle and the quadrates lumborum muscle at L5-S1 compared to at L4-5 and above, L5 and below may not be used for lateral approaches to the lumbar spine. Benglis et al. also found an obvious dorsal to ventral migration of the lumbar contribution to the lumbosacral plexus within the psoas muscle from L2 to L5 in their cadaver studies.[12]

Using the lateral transpsoas approach in cadaveric dissection to identify the structures at risk with transpsoas K-wire and dilator placement, Banagan et al. found a more serious potential anatomic problem[13]: The nerve roots and the genitofemoral nerve could be at risk in all their dissections in which the transpsoas approach is re-created. K-wire placement caused damage in 25% of cases at L3-4 and L4-5, including one direct L4 nerve root piercing. It was also found that the lumbar plexus was under tension after sequential dilator placement even when no direct injury happened during insertion. In addition to the lumbar plexus, the sympathetic chain was identified in the anterior third of the psoas over the disc spaces of L1 to L4, putting it at risk of potential damage with the transpsoas approach. Using a similar approach, Davis et al. found the femoral nerve is consistently at risk as it crosses the L4-5 interspace and can be compressed against the L5 transverse process when retractors are opened during the XLIF/DLIF procedures.[14]

Using a morphometric analysis of the ventral lumbar nerve roots and large vessels with the vertebral end plate, from hundreds of MRI studies, Regev et al. found the overlap of either roots or large vessels with the end plates gradually increased from L1-2 to L4-5. At the L4-5 level, the overlap can reach up to 87%, resulting in a very narrow corridor for potential LLIF procedures.[15] Scoliosis was found to further decrease the potential safe corridor for LLIF. The preceding anatomic studies indicated the importance for neuromonitoring when establishing safe passage through the psoas muscle during LLIF procedures.

Surgical Technique

OPEN LLIF

Access to the lateral lumbar spine using an open approach allows several potential surgical dissection planes. In the LEC approach popularized by Larson et al., the lumbar spine is accessed with the plane of dissection posterior to the quadrates lumborum and anterolateral to the erector spinae muscles.[2] The erector spinae muscle group is elevated and retracted medially to expose the lateral elements of the spine. In 2002, Wolfla et al. described a retroperitoneal L2 to L5 lumbar interbody fusion using a true lateral trajectory to treat symptomatic nonunion.[16] The access to the lumbar spine was provided by retraction of the psoas and quadrates lumborum muscles posteriorly. In their series of 15 patients with painful pseudarthrosis from 1 or more (average 2.1) previous posterior lumbar operations, 87% had significant improvement after open LLIF, and a 90% radiographic fusion rate was reported.

In open LLIF, the patient is placed in the lateral decubitus position in a plane perpendicular to the floor to facilitate obtaining lateral radiographs (Fig. 172-4). Generally, a left-sided approach is preferred for preferential retraction of the descending aorta as opposed to the inferior vena cava. In addition, for upper lumbar levels, the liver may prevent right-sided exposure. The ipsilateral lower extremity is preferably flexed at the hip to reduce tension on the psoas muscle.

A standard left flank retroperitoneal exposure is performed based on the required level of exposure. Access can reliably be provided from L2 to L5, hindered above by the crura of the diaphragm and below by the ileum. After skin incision, the external oblique muscle and fascia are exposed and divided along its fibers. The underlying internal oblique and transverse abdominis muscles are then transected. After the deep fascia of the transverse abdominis is opened, the retroperitoneal space is entered. Blunt finger dissection is used to strip the peritoneum retroperitoneal contents anteriorly away from the quadratus lumborum and psoas muscles (Fig. 172-5), exposing the anterior spinal column and the great vessels. The psoas and quadratus lumborum muscles are then retracted dorsally, exposing the lumbar vertebrae. The ureter, genitofemoral nerve and sympathetic chain are identified and protected. The posterior border of the ALL is identified to serve as an important landmark later for the placement of the interbody fusion material. To perform interbody fusion, all disc spaces to be fitted with instrumentation are opened from the lateral border of the ALL to the base of the transverse process; the discs are then removed using angled curettes and rongeurs. During this step, the assistant needs to retract the psoas muscle out of the way manually. Retraction of the psoas should be from ventral to dorsal to protect the traversing nerve roots in the psoas muscles.

After the disc space is prepared, a large implant (e.g., a polyethylethylketone, or PEEK, cage) is chosen to ensure solid engagement to the bone surface with maximal height

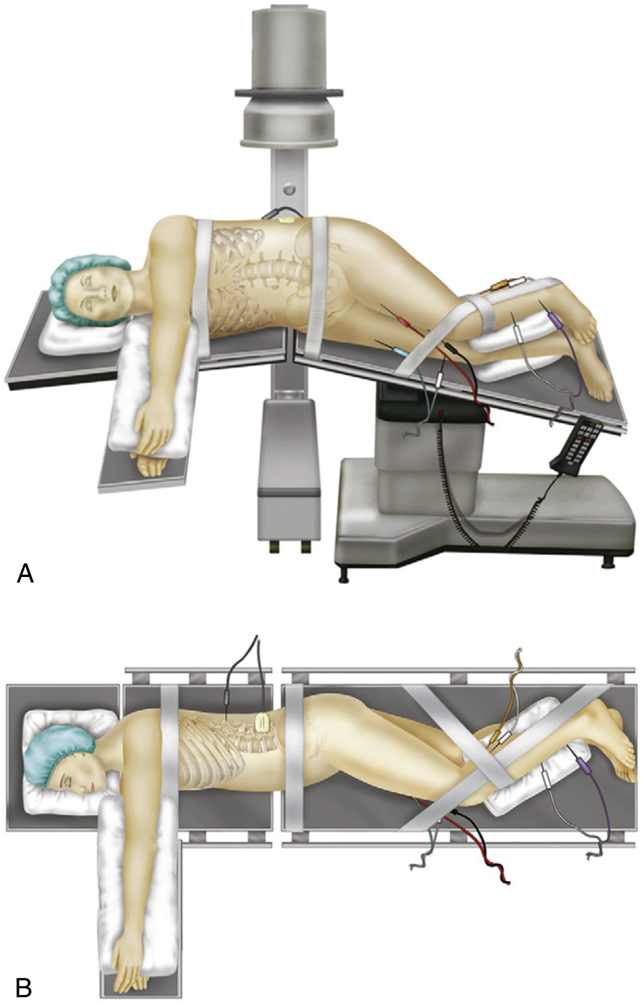


FIGURE 172-4 Typical patient positioning for the lateral lumbar approach. A, The patient's arms are supported and padded. The table can be flexed at the lumbar level to allow for easier access. The table should also be adjusted so that the C-arm can be positioned adequately for visualization of the interested level. B, The top leg should be gently flexed at the hip and knee to allow for psoas muscle relaxation. *(Courtesy of Medtronic, Memphis, TN.)*

restoration. Lateral radiography is used to confirm a true lateral trajectory, and then the tang retractor is placed into the disc space laterally.

One of the benefits of the open lateral lumbar approach is the possibility of performing a vertebrectomy for extensive lumbar vertebral infection or neoplasm decompression. In addition, by placing an angled retractor into the disc space of L5-S1 at a 35- to 45-degree angle from the true lateral plane, it is possible to place a cage into the L5-S1 disc space using the same incision and thus avoid the iliac crest. However, this is generally more difficult to perform compared to ALIF at L5-S1.

MINIMALLY INVASIVE LLIF (XLIF/DLIF)

Minimally invasive LLIF involves anatomic exposure similar to that of open LLIF but incorporates multiple additional steps to increase safety and minimize exposure. The key steps include preoperative planning, needle electrode setup, patient positioning, fluoroscopic localization, dissection to the psoas muscle, neuromonitoring through the

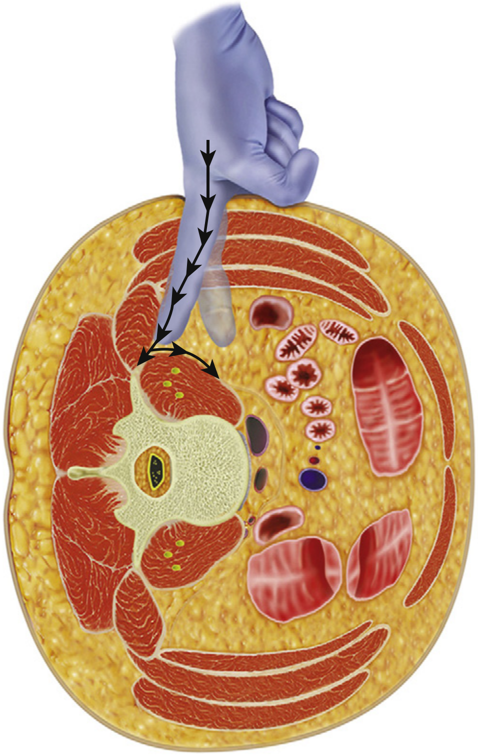


FIGURE 172-5 Anatomic layers encountered with the lateral lumbar approach. The layers encountered include the external and internal oblique muscles, the transverse abdominis, deep fascia, and retroperitoneal fat. Once in the retroperitoneal space, the quadratus lumborum muscle can be palpated and identified dorsally while the psoas muscle is identified ventrally. *(Courtesy of Medtronic, Memphis, TN.)*

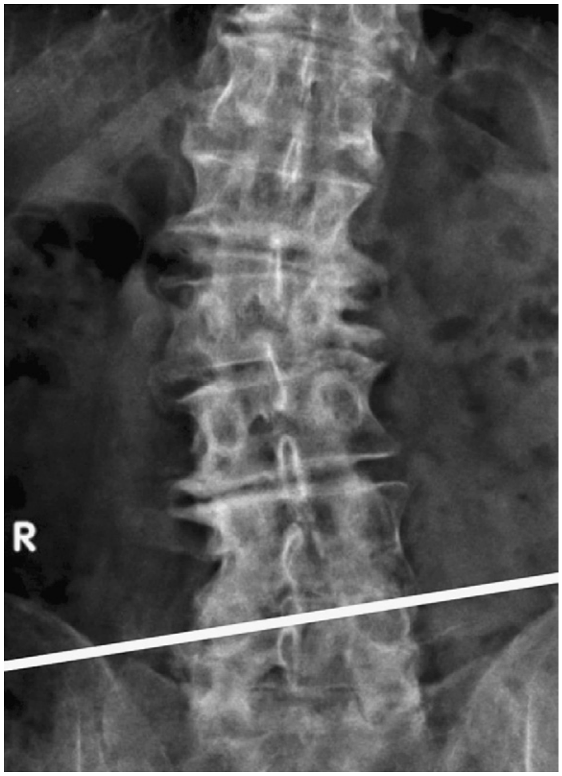


FIGURE 172-6 AP x-rays should be reviewed preoperatively to assess differences in iliac crest heights, especially in patients with scoliosis. The side of surgical approach should be selected on the side of the lower iliac crest to avoid bony obstruction.

psoas muscle, sequential dilation and retractor placement, disc preparation, implant insertion, and closure.

Preoperative Planning

Preoperative anteroposterior (AP) and lateral lumbar x-rays must be studied carefully to identify any anatomic abnormalities that might hinder access to the lateral side of the vertebral column. For example, a high iliac crest at L4-5 may prevent straightforward access to the L4-5 disc space from lateral approaches. This variant occurs more frequently in men. Although infrequent, a deep-seated L4-5 disc space could be difficult to reach via a direct lateral approach, even if table breaking options are employed. Obtaining standing AP x-ray images with the patient bending laterally can help determine whether or not a level can be accessed above the iliac crest. Furthermore, long 11th and 12th ribs might prevent straightforward lateral access to high lumbar disc spaces. In these circumstances, an intercostal approach or partial rib resection may be required.

Preoperative planning also includes choosing the side of the approach. Usually, minimally invasive LLIF is approached from the left side. However, surgeons should also consider ease of access and surgeon preference in determining which side to approach. Preoperative AP and lateral x-ray films need to be examined to determine the side that appears to have easier access, for example, the side with a low iliac crest or shorter lower ribs (Fig. 172-6). In the case of degenerative scoliosis, the approach is usually from the side of the convexity.

Needle Electrode Setup

Because of potential injury to the lumbar plexus during the transpsoas approach, real-time EMG monitoring of the lumbar plexus and roots must be implemented to ensure safe passage through the psoas muscle during the procedure. The anesthesiologist uses only a short-acting neuromuscular blocking agent for induction; subsequently, the patient must not be paralyzed for the remainder of the procedure to facilitate EMG monitoring. EMG of the medial and lateral quadriceps, anterior tibialis, gastrocnemius, and adductor muscles on the side of surgery is standard. Stimulating electrodes should be available to provide additional information, along with free-running real-time EMG. Proprietary real-time EMG monitoring can be carried out by the NeuroVision system from NuVasive, which provides automated neurophysiologic monitoring. NeuroVision provides neuroproximity information via algorithms that stimulate and interpret up to five times per second. The XLIF dilators from the same company have stimulating electrodes at the tips and a stimulating clip attached to the opposite end, allowing real-time NeuroVision EMG monitoring. The Nerve Integrity Monitor (NIM) Eclipse system from Medtronic provides similar information when used with NIM X-Pak probes during transpsoas dilation.

Patient Positioning

The patient is placed on a radiolucent operating table in a true lateral position. The iliac crest is aligned with the break of the radiolucent surgical table. An axillary roll is placed to protect the neurovascular structures in the axilla. Padding is placed between the arms to ensure they

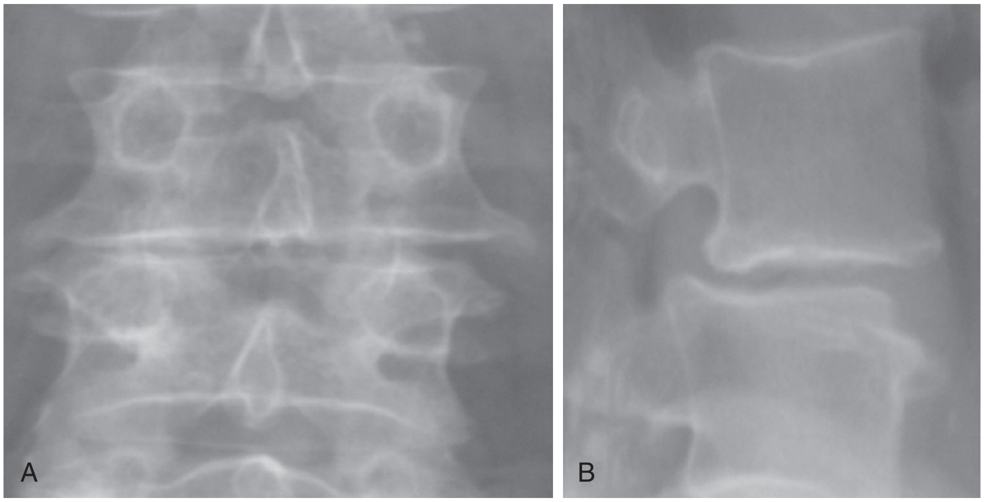


FIGURE 172-7 Intraoperative fluoroscopic imaging should be aligned to allow straight AP and lateral visualization. A, Straight AP imaging allows clear visualization of both pedicles with centered spinous processes and distinct end plates. B, Straight lateral imaging allows clear visualization of the disc space with distinct end plates.

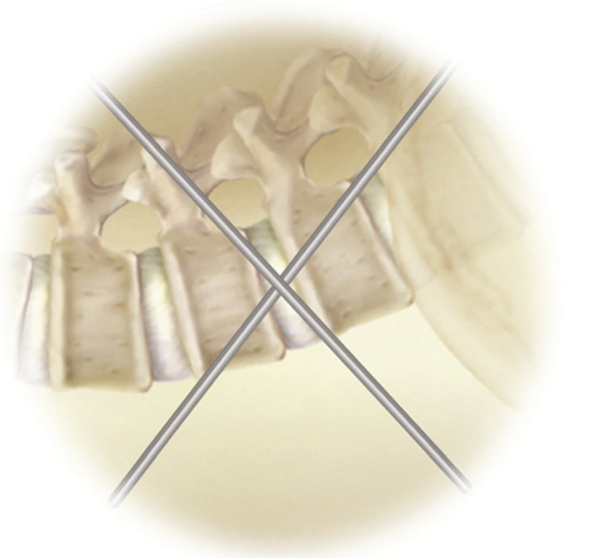


FIGURE 172-8 Crossed K-wires can be used on the skin surface to pinpoint the center of the disc space on lateral fluoroscopic imaging. At L4-5, the K-wires should be centered on the middle of the anterior third of the disc space to avoid descending nerve roots. *(Courtesy of Medtronic, Memphis, TN.)*

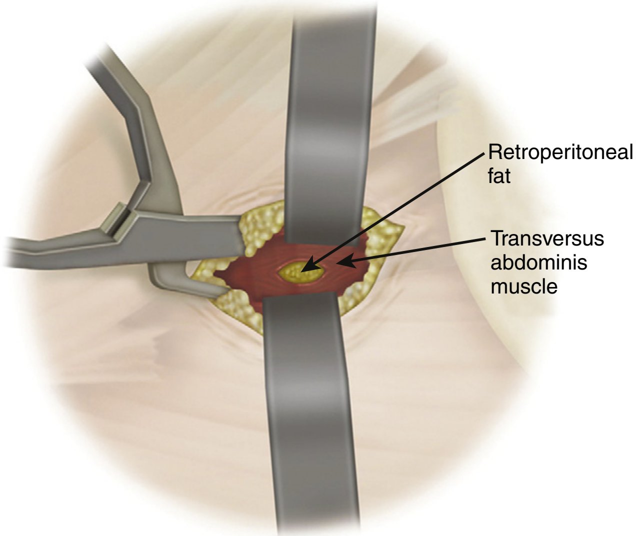


FIGURE 172-9 A 3-cm incision is made in obliquely, and soft-tissue exposure is performed with Bovie electrocautery, a blunt finger, and dissecting forceps. *(Courtesy of Medtronic, Memphis, TN.)*

remain suspended in the neutral position. The top leg of the patient should be flexed to relax the psoas muscle and prevent spreading of the nerves across the psoas muscle. Padding is also placed beneath and between the legs from the knees distally (see Fig. 172-4). The patient is then secured to the surgical table with tape. The patient is placed in a slight reverse Trendelenburg position, the head of the table is dropped, and a slight flexion is applied to the surgical table. This maneuver allows better access to the lumbar spine by increasing the distance between the iliac crest and the lower rib, as well as by opening the disc space to be entered.

The patient must be placed in a plane perpendicular to the floor so that lateral fluoroscopy can provide good-quality, unobstructed images of the disc space of interest. First, a true AP image should be obtained to ensure the patient is positioned in a true lateral position. On the AP x-ray, clear and distinct pedicles that are equidistant from the spinous process should be visible (Fig. 172-7A). Then, a lateral x-ray is obtained, and clean, distinct end plates should be seen (Fig. 172-7B). It is critical that the C-arm remain in the 0- and 90-degree positions at all times to ensure a safe lateral working channel across the disc space. For multilevel cases, the surgical table is rotated independent of the C-arm to adjust images for each level, and biplanar fluoroscopy or equivalent is highly recommended.

Fluoroscopic Localization

Fluoroscopy is used to confirm the target segment and mark the initial incision by using bisecting K-wires laid on top of the skin (Fig. 172-8). For a single-level case, the skin is marked over the midsection of the target disc, and a 3-cm horizontal, vertical, or oblique incision is made (Fig. 172-9). For a two-level case, the skin is marked over

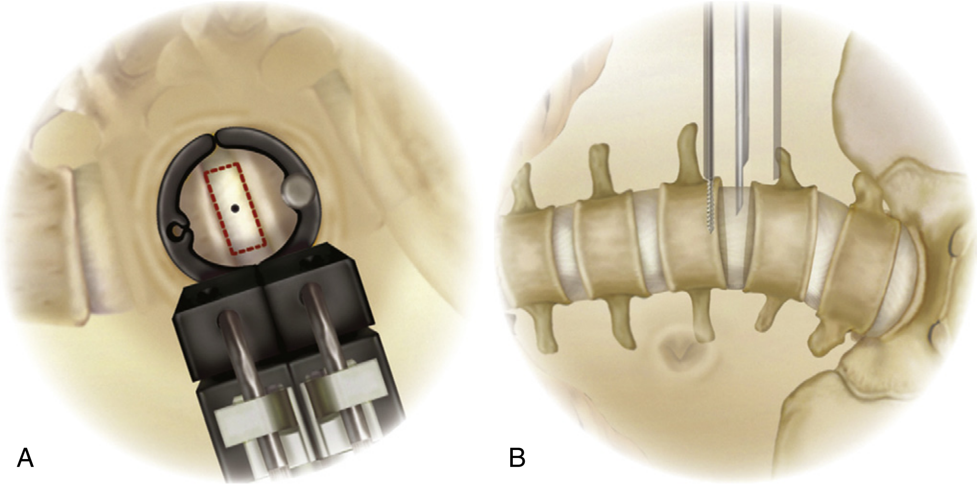


FIGURE 172-10 In the minimally invasive LLIF approach, a tubular expandable retractor is centered over the middle to anterior third of the disc space. A, The retractor should not extend too far into the posterior third of the disc space to avoid injury to descending nerve roots and should not extend beyond the ventral vertebral body border to avoid injury to vascular structures. B, After the retractors are docked appropriately, the disc is incised with a scalpel in preparation for discectomy. *(Courtesy of Medtronic, Memphis, TN.)*

the midsection of the intervening vertebral body. It may be possible to access multiple levels through one vertical skin incision, depending on the anatomy and curvature of the spine. Although it is possible to use a single incision for multiple levels, separate dilations through the psoas must be performed for each operative disc space.

Dissection to the Psoas Muscle

After a single skin incision, the subcutaneous fat layers are dissected until the abdominal musculature is reached. Hemostasis is achieved using monopolar cautery, and a small self-retaining retractor is used to facilitate initial dissection of the skin and subcutaneous layer. The first plane encountered is the external oblique fascia, the only layer that needs to be sharply incised. A Kelly clamp is then used to bluntly spread through the fibers of the external oblique, internal oblique, and transversalis muscles. All dissection should be parallel to the muscle fibers, which run in opposite directions in each plane. After bluntly penetrating the transversalis fascia, the yellow retroperitoneal fat is exposed. At this point, palpation of the quadratus muscle and the tip of the transverse process confirms the correct retroperitoneal plane. Palpation is then used to define the plane from the internal abdominal wall posteriorly down to the psoas muscle, which can then be visualized. The retroperitoneal fat and peritoneal contents are swept forward with the surgeon's finger or a peanut elevator to allow direct access to the psoas muscle (see Fig. 172-5).

Neuromonitoring Through the Psoas Muscle

After a safe retroperitoneal pathway to the psoas has been established, the stimulating EMG probe (NIM X-Pak Probe, Medtronic, or NeuroVision dilator, NuVasive) is guided down to the psoas muscle while the surgeon's finger protects the peritoneal membrane. As previously mentioned, the nerves of the lumbar plexus are located mostly in the posterior half of the muscle. The stimulating probe should thus target the anterior half to third of the disc space to avoid damage to neural structures, but it should also remain posterior enough to avoid vascular structures. Lateral fluoroscopy is used to guide the probe into the appropriate position. As the muscle fibers are split from probe insertion, a current is delivered to detect any intervening neural structures. Monitoring is performed using 6 to 8 mA of stimulation. If an EMG response is generated at this level, the stimulating probes should be repositioned slightly anterior until a nerve-free pathway is located. Both systems allow nerve proximity mode detection. In this mode, the system sends out a cycling current continuously to search for the stimulus threshold required to elicit an EMG response. The displayed current value decreases as the stimulating probe approaches a nerve. Ensuring threshold values above a certain level (usually 8 mA) is recommended. After the probe has safely dissected through the psoas, the probe tip, as well as a portion of the insulated cannula, is tapped into the disc space to secure its location. AP x-rays are taken to confirm proper probe alignment into the disc space. A guidewire is then placed through the cannula into the desired disc space, and its position is again confirmed with fluoroscopy.

Dilation and Retractor Placement

With the guidewire in place, sequential dilation spreads the fibers of the psoas up to a diameter of 22 mm, with free-running EMG active to detect any mechanical affect on the nerve roots. With the NeuroVision system (NuVasive), the dilators can continue to provide real-time EMG monitoring during each dilation, because they have stimulating electrodes at their tips. Care must be taken to ensure that each dilator reaches the disc space and to minimize the amount of residual muscle at the end of the dilators. If needed, fluoroscopy can be used to confirm that each dilator has reached the disc space. The first dilator may be extended slightly into the disc space to ensure complete dilation through the psoas muscle. After the largest dilator is placed, the appropriate retractor blades are selected based on the depth from skin to the disc. The retractor blades are placed onto the base, and the entire assembly is then placed over the dilators. The retractor is advanced with a back-and-forth twisting motion and only gentle downward pressure through the fascia and muscle. This technique helps ensure that the fascia and muscle fibers are not pulled down into the surgical corridor. After the retractor is docked on the lateral aspect of the disc space, the system is secured to the operating table and expanded (Fig. 172-10). The retractor should not be expanded past the midpoint of the vertebral body where the segmental vessels off the descending aorta typically course. In the Medtronic system, both retractor blades have a stability pin system to prevent retractor migration during the ensuing procedure. Prior to pin placement, it is prudent to use the stimulating probe to test both pin channels to ensure a nerve-free pathway. Afterward, the pin is threaded into the channel. With the stability pin in place, the dilator tubes are removed. A final lateral image is taken to confirm proper retractor placement over the lateral spine. With the retractor system in the correct position, an attached light source illuminates the surgical corridor.

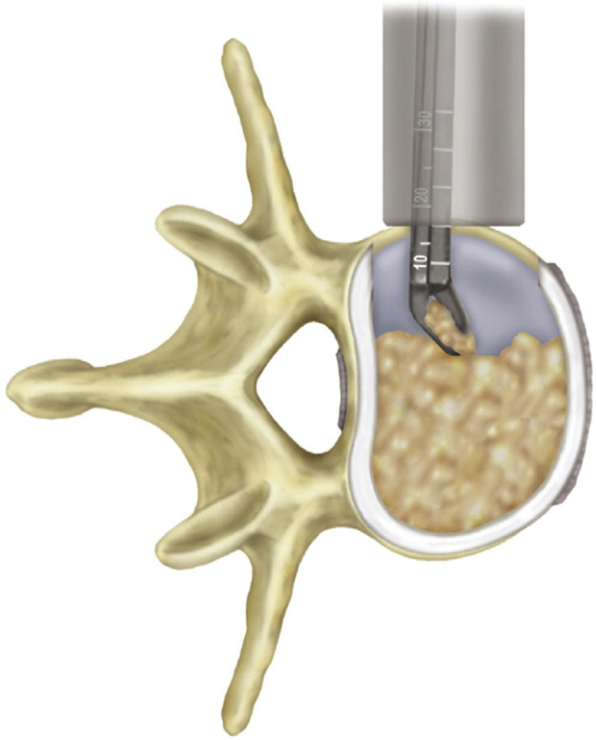


FIGURE 172-11 Lateral discectomy is performed with Cobb elevators to detach the disc off of the end plates; a variety of curettes and pituitary rongeurs are also used. Nearly complete discectomy can be achieved with preservation of the AP longitudinal ligaments. *(Courtesy of Medtronic, Memphis, TN.)*

Discectomy and End-Plate Preparation

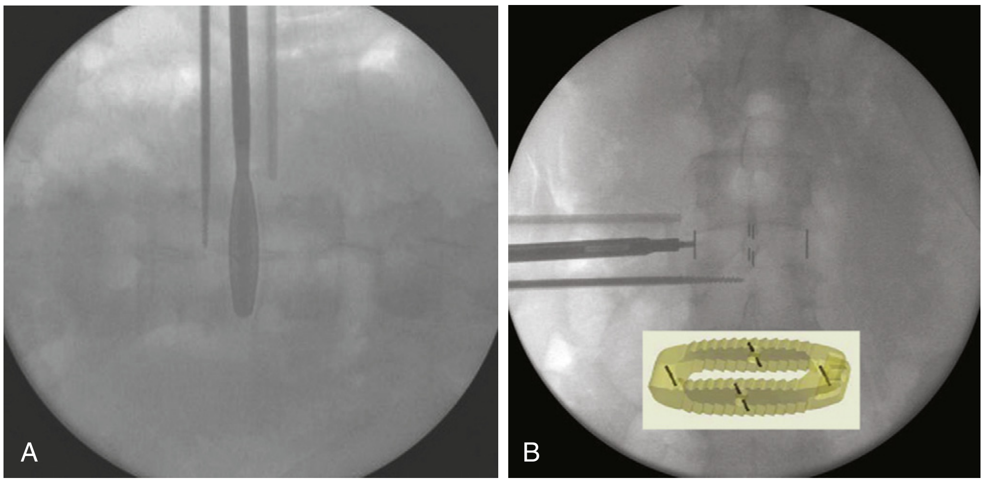
Typically, a thin layer of soft tissue remains at the base of the retractor blades. The stimulating ball-tip probe can be used again to stimulate all four quadrants at the retractor base and thus identify any nerve structures that may be present in this residual muscle. Once the annulus is visualized, a lateral annulotomy is performed using a bayoneted scalpel. The discectomy is completed using pituitary rongeurs and curettes (Fig. 172-11). A large Cobb is passed along both end plates to the annulus at the contralateral side to detach the disc. A mallet is then used to gently release both the superior and the inferior aspects of the contralateral annulus. This step is critical to ensure adequate distraction and coronal alignment. It is especially important for deformity correction. Both the ALL and the posterior longitudinal ligament are preserved in most circumstances. Attention is then turned to the end plates, which must be completely cleaned of cartilaginous disc without destruction of the cortical end plates. Shavers large enough to clean but small enough to avoid decortication are used to remove any residual disc material. Finally, care must always be taken to ensure the patient remains in a true lateral position and the instrument trajectory remains perpendicular to the floor to avoid potentially catastrophic injury to vessels or nerve structures.

Interbody Implant Placement

The disc space is sequentially distracted with trials until adequate disc space height is obtained and foraminal size is restored. Each trial is passed through the retractor and impacted into the disc space. A properly sized trial is centered on the spinous process and should span the ring apophysis to reach fully across the vertebral body end plate (Fig. 172-12A).

Once trialing is complete, the central cavity of the corresponding implant is filled with graft material. A mallet is then used to gently insert the implant under AP (or better, biplanar) fluoroscopic guidance. After the implant is positioned in the center of the disc space from a medial/lateral perspective, the inserter is unthreaded from the implant and removed. Placing the implant over the outer rim of the end plate on each side provides maximum support to the

FIGURE 172-12 A, After discectomy is completed, trial spacers are used to size the disc space for interbody grafting. B, Grafts should be placed evenly so that maximal end-plate coverage is attained. The PEEK cages usually used for LLIF have radiopaque markers (inset) to allow visualization of the graft in situ and thus to confirm maximal coverage of the cortical apophyseal ring.



strength of the ring apophysis (Fig. 172-12B). After implant insertion, the stability pin is removed, the retractor system detached, and the retractor blades are carefully removed. The surgical site is irrigated, and the fascia over the external oblique is closed with interrupted Vicryl sutures. Finally, the subcutaneous layers and skin are closed routinely.

SUPPLEMENTAL LATERAL PLATE FIXATION VS. PERCUTANEOUS POSTERIOR FIXATION

After a minimally invasive LLIF procedure, patient can be repositioned for posterior decompression and/or posterior fixation when deemed necessary. Commonly, percutaneous or open pedicle screw instrumentation is placed (Fig. 172-13). One alternative for supplemental reinforcement of the operative level is to use the lateral plating system such as the extreme lateral plate (XLP, NuVasive), in which case patient repositioning is no longer necessary, decreasing the operative time and the morbidity associated with a second operation. However, the effectiveness of the XLP system has not been compared with posterior pedicle screw placement in any systematic way.

COMPARISON OF LUMBAR INTERBODY TECHNIQUES

The described minimally invasive LLIF provides many advantages over AP approaches. Compared to anterior approaches, mobilization of the abdominal contents and great vessels is not required, thus avoiding injury to the hypogastric sympathetic plexus, gastrointestinal, and genitourinary systems. Complications such as bowel injuries, adhesions, hernias, and retrograde ejaculation are effectively avoided. In addition, the necessity of an access surgeon is eliminated. One additional benefit is the preservation of the ALL, which might avoid the destabilizing effect of sectioning the ALL in the ALIF approach.

Compared to the posterior approaches (TLIF and PLIF), retraction of the neural elements and exploration of the spinal canal are minimized, thus avoiding the potential complications for injury to the spinal cord and/or nerve roots. Furthermore, during posterior approaches, extensive muscle stripping and resultant denervation can lead to muscle atrophy, chronic dysfunction of the lumbar paraspinal musculature, and failed back syndrome. Although no direct mechanical comparison has been made, the lateral approach preserves the facets and posterior tension band as compared to the posterior approaches, thus holding a theoretical advantage of preserved stability, especially when direct neural decompression is not needed. Another benefit of the lateral approach is the ability to place a large interbody implant. Larger implants have been shown to more effectively restore foraminal dimensions, allowing better nerve root decompression. A larger implant also distributes end-plate stress over a larger surface area, thus lowering mechanical stresses at the bone–implant interface.

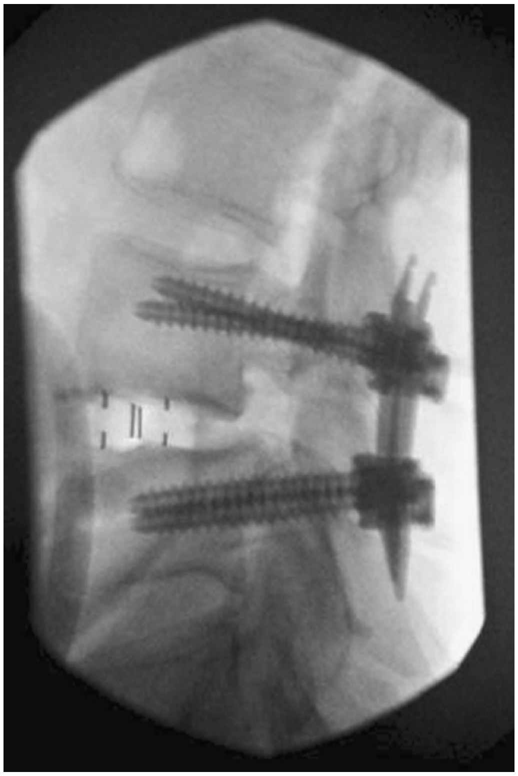


FIGURE 172-13 Posterior fixation with pedicle screw instrumentation is commonly used to supplement LLIF procedures. Posterior instrumentation can be performed openly or percutaneously with either pedicle or facet screws.

Limitations and Potential Complications of LLIF

Compared to anterior or posterior lumbar fusion procedures, LLIF is mostly limited to levels above L5, a clear disadvantage given the preponderance of degenerative lumbar disc disease at the L5-S1 level. An abnormally high iliac crest and risk of nerve injury may prevent access even to the L4-5 intervertebral disc area, necessitating careful study of good-quality preoperative images. Furthermore, it cannot directly address posterior pathologies such as disc rupture or severe stenosis from facet or ligamentum hypertrophy, which may require an additional posterior approach for posterior decompression.

One of the major concerns of LLIF is the potential of damaging the lumbar plexus that traverse the psoas muscle. One recent anatomic study identified that the L4 nerve root, genitofemoral nerve, and sympathetic chains are often at risk of direct piercing or stretch injury during routine transpsoas K-wire and dilator placement, increasing concern over the safety of the direct transpsoas approach.[13] Real-time EMG systems are designed to minimize this risk. To date, no studies have been done to validate the effectiveness of these systems in preventing lumbar plexus injury. Real-time EMG can only effectively identify a safe entry point to the intervertebral disc; however, the large dilators/retractors that allow passage of large lateral implants compress important nerve structures in the psoas muscle once it is fully opened. It is estimated that the femoral nerve is under compression 100% of the time during the lateral transpsoas approach.[14] It is most at risk at the L4-5 interspace, with significant risk of being compressed against the L5 transverse process. As such, the actual retraction time must be monitored to minimize the risk of femoral nerve injury. An L4 neurogram might be able to show the trajectory of the L4 root/femoral nerve as it crosses the L4-5 intervertebral disc space, which might minimize L4 nerve root damage during the lateral transpsoas approach.[17] Furthermore, trauma to the psoas muscle can produce hip pain and weakness.

The other potential complication for LLIF is bowel injury. At higher levels, with the incursion of the retractors, it is possible to trap the bowel in the retractors. However, this does not seem to be a major problem from the published series.

Thus far, the complication profile associated with LLIF procedures has only been published in a limited number of series, and it appears that the approach-associated complications are generally quite benign. Temporary postoperative groin or thigh dysesthesias are among the most common complaints. Knight et al. published results from a series of 58 patients who underwent LLIF and found 8 approach-related complications (13.8%), the majority being transient meralgia paresthetica.[18] Two patients (3.4%) in their series suffered from L4 nerve injury that showed residual motor deficits at 1 year postoperatively. In the series by Anand et al. with degenerative lumbar scoliosis, 3 of 12 patients (25%) experienced transient groin or thigh dysesthesias and 1 of 12 patients (8.3%) had quadriceps weakness that lasted 6 weeks.[9] Transient hip flexor weakness can be seen up to 50% of the time.[19] Reported complication rates and profiles appear to be comparable with anterior or posterior approaches. However, due to the limited systemic studies on LLIF-related complications, the benefit of LLIF must be carefully weighed against potential complications individually to provide the best clinical results for patients. The limitations of LLIF can occasionally be circumvented by combining it with other minimally invasive procedures. It was reported that by combining multiple minimally invasive procedures, multisegment deformity correction can be achieved[9] with less blood loss and morbidity than in open procedures.

In summary, LLIF offers many advantages over traditional anterior or posterior approaches, especially in a carefully selected patient group. The inherent limitations and potential complications associated with this approach must be fully understood by the spine surgeons and discussed thoroughly with the patients prior to the surgery. The lateral approach should be in the armamentarium of the surgeon, in addition to AP approaches. Minimally invasive techniques (XLIF/DLIF) have obvious risks and advantages, but overall, they can provide excellent interbody access from L2 to L4 safely.

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