eXtreme Lateral Interbody Fusion (XLIF®)

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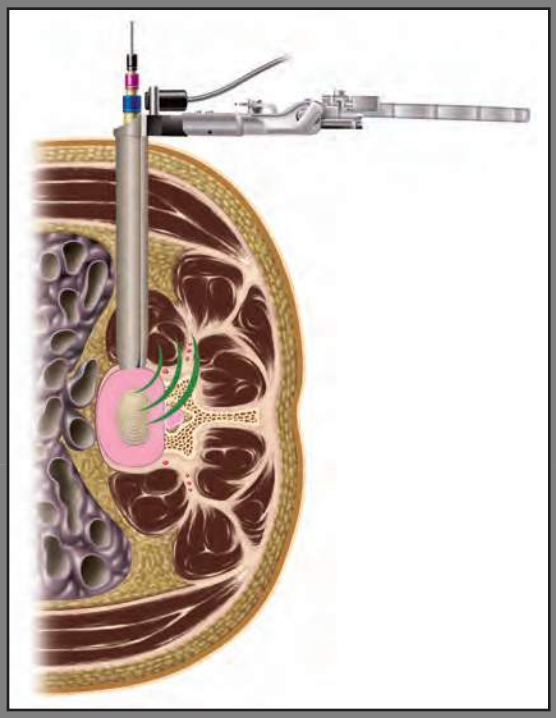
Part II

Surgical Techniques and Clinical Applications



8

Surgical Technique: eXtreme Lateral Interbody Fusion

Luiz Pimenta ▪ Thomas D. Schaffa

Attention to detail and accurate surgical technique are of the utmost importance for surgeons learning the extreme lateral interbody fusion (XLIF®, NuVasive®, Inc., San Diego, CA) surgical procedure. The XLIF procedure can be broken down into five key steps, which, if adhered to meticulously, produce safe and reproducible results (Box 8-1). By following the guidelines in this chapter, we have had continued success with lateral access surgery for many patients and for multiple surgical indications. Indications include any pathology requiring anterior column stabilization in the thoracolumbar spine above L5. Relative contraindications include pathologies at the L5-S1 level (because of limitations of access around the iliac crest) and high-grade spondylolisthesis (≥grade 3). Prior retroperitoneal surgery need not preclude secondary access via XLIF, although caution is required when approaching the upper lumbar levels in patients who have undergone bilateral renal surgery. In this chapter, we focus on the steps of the technique, with particular attention to the nuances that contribute to a successful outcome.

BOX 8-1 Five Key Steps for Performing the XLIF Procedure

1. Appropriate patient positioning
2. Retroperitoneal access
3. Transpsoas access
4. Disc space preparation
5. Implant insertion

Surgical Considerations

The XLIF procedure allows access to the spine via a direct lateral retroperitoneal approach. The anatomic landmarks the surgeon should consider when preparing for this technique include the iliac crest, the twelfth rib, and the lateral border of the erector spinae muscles. Two small incisions are made during this procedure. The first incision, located near the lateral border of the erector spinae muscles, is used to access the retroperitoneal space and safely guide the initial NeuroVision® Dilator (NuVasive, Inc.) to the psoas muscle. The second incision, located in a direct lateral position, is used to place the Dilators and Retractor and provides disc space access. This two-incision technique was specifically developed to offer simple and efficient access to the spine and to minimize the potential for peritoneal injury. If cosmesis is a concern, an advanced technique using a single skin incision with two fascial incisions can be used to the same effect.

To successfully complete the XLIF technique, the following equipment is required:

- Radiolucent, bendable surgical table
- C-arm
- Light source
- MaXcess® III Access System (NuVasive, Inc.)
- MaXcess Articulating Arm
- MaXcess Disposable Kit
- XLIF Instruments
- Anterior/lateral general instruments
- NeuroVision® JJB System
- NeuroVision XLIF Disposable Module

Step One: Patient Positioning and Operating Room Setup

The patient is placed on a bendable surgical table in a direct lateral decubitus position, with the greater trochanter directly over the table break. A true lateral (90-degree) position is critical to the safety and reproducibility of lateral access surgery. In a lateral decubitus position the abdominal contents fall forward, away from the approach to the disc space. This simplifies the approach in even the heaviest patients. A true lateral position allows the surgeon to work directly perpendicular to the floor to ensure a safe trajectory across the disc space and to avoid anterior or posterior structures. After initial positioning, the patient is secured with tape (Fig. 8-1).

This configuration ensures that the pelvis tilts away from the spine, allowing access to all lumbar levels, particularly L4-5.

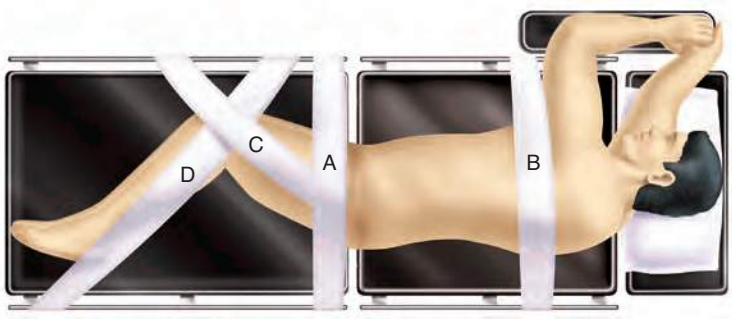


FIG. 8-1 The patient is positioned in a direct lateral decubitus position and secured with tape just below the iliac crest *(A)*, over the thoracic region *(B)*, from the iliac crest to the knee and to the table *(C)*, and from the table to the knee, past the ankle, and to the table *(D)*.

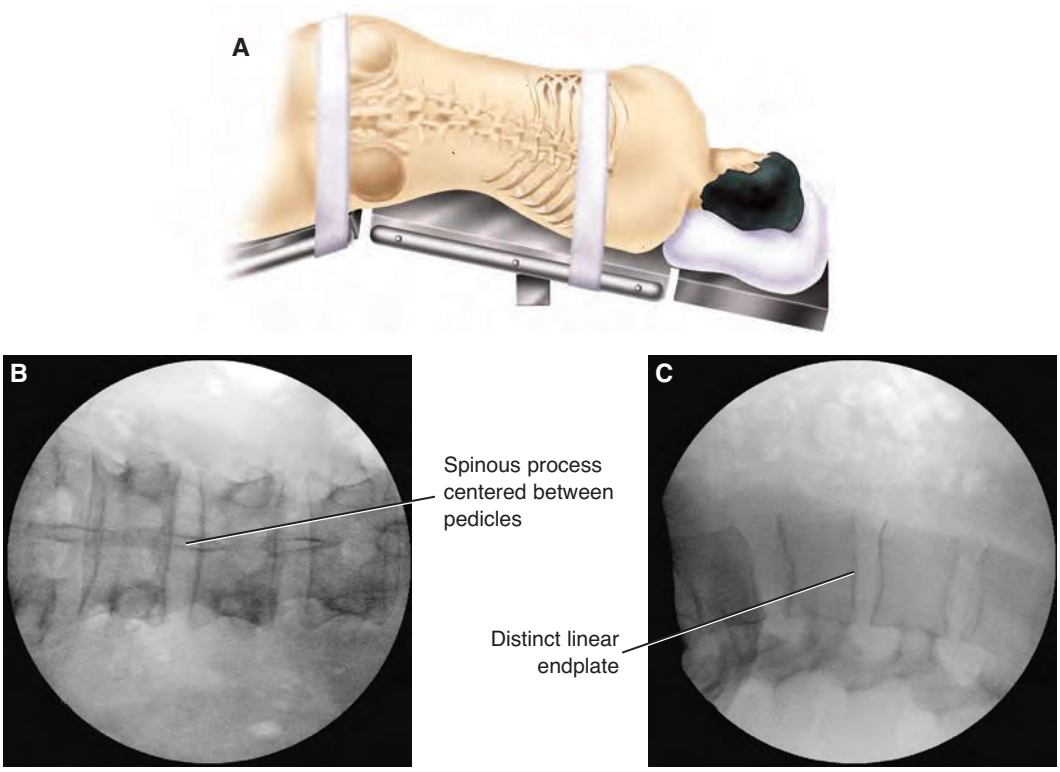


FIG. 8-2 **A,** The surgical table is flexed to increase the distance between the iliac crest and the ribs to gain direct access to the disc. **B** and **C,** True anteroposterior and true lateral fluoroscopic images confirm patient positioning.

Using fluoroscopy to verify the location, the surgical table should be flexed to increase the distance between the iliac crest and the ribs and to allow direct access to the disc (Fig. 8-2, *A*). Once the patient has been secured with tape, the table can be adjusted so that the C-arm provides true anteroposterior and true lateral images (Fig. 8-2, *B* and *C*). The table should be readjusted as the surgeon accesses each level to maintain this relationship, particularly in cases of rotational deformity. Careful attention to imaging ensures that the patient is in a

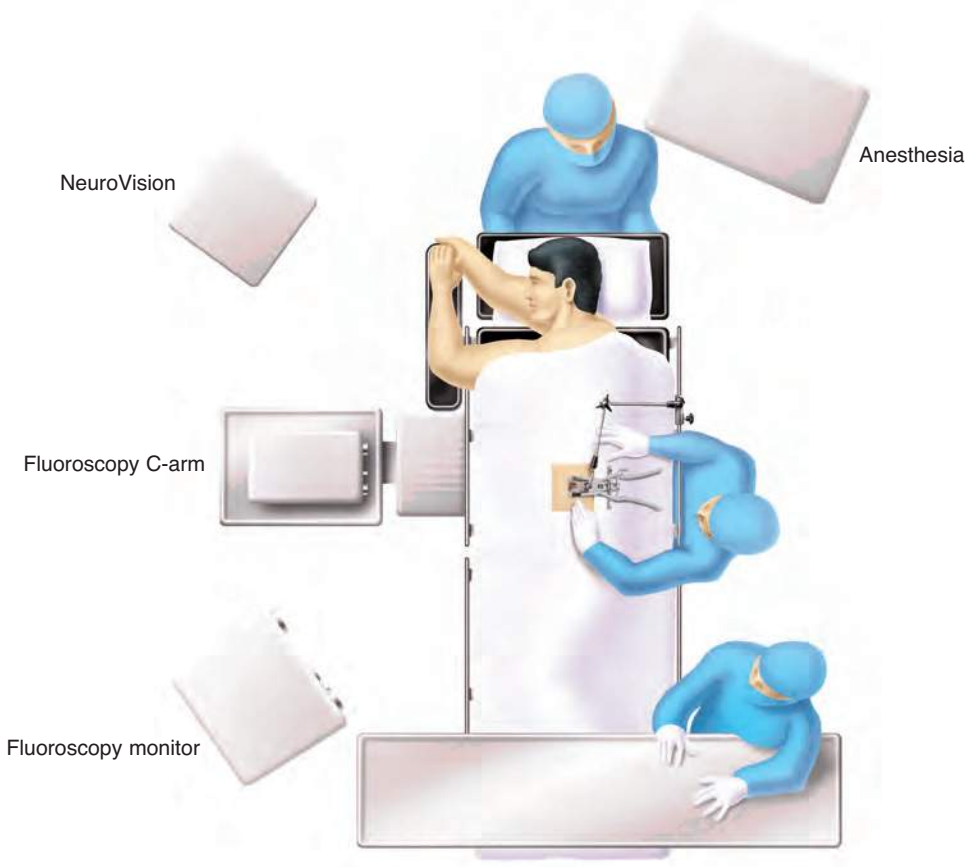


FIG. 8-3 Operating room setup, with the fluoroscopy monitor and the NeuroVision Control Unit placed opposite the surgeon for an unobstructed view.

true lateral position, which is achieved by rotating the table rather than the C-arm. The NeuroVision Control Unit should be placed opposite the surgeon to provide an unobstructed view (Fig. 8-3).

ANATOMIC LANDMARK IDENTIFICATION AND INITIAL INCISIONS

After preparing the patient aseptically, the disc space is localized using lateral fluoroscopy. This is accomplished by crossing two K-Wires over the pathologic level and centering them over the indicated disc space (Fig. 8-4, *A* and *B*). A mark on the skin is made at the intersection of the K-Wires to serve as the location of the skin incision for the operative corridor. Another mark is made on the skin at a posterolateral location, approximately midway between the ilium and the rib cage. Typically, this mark is a finger length's distance from the lateral incision and just lateral to the erector spinae muscles (Fig. 8-4, *C*). The retroperitoneal space is accessed through this incision with blunt scissors and finger dissection.

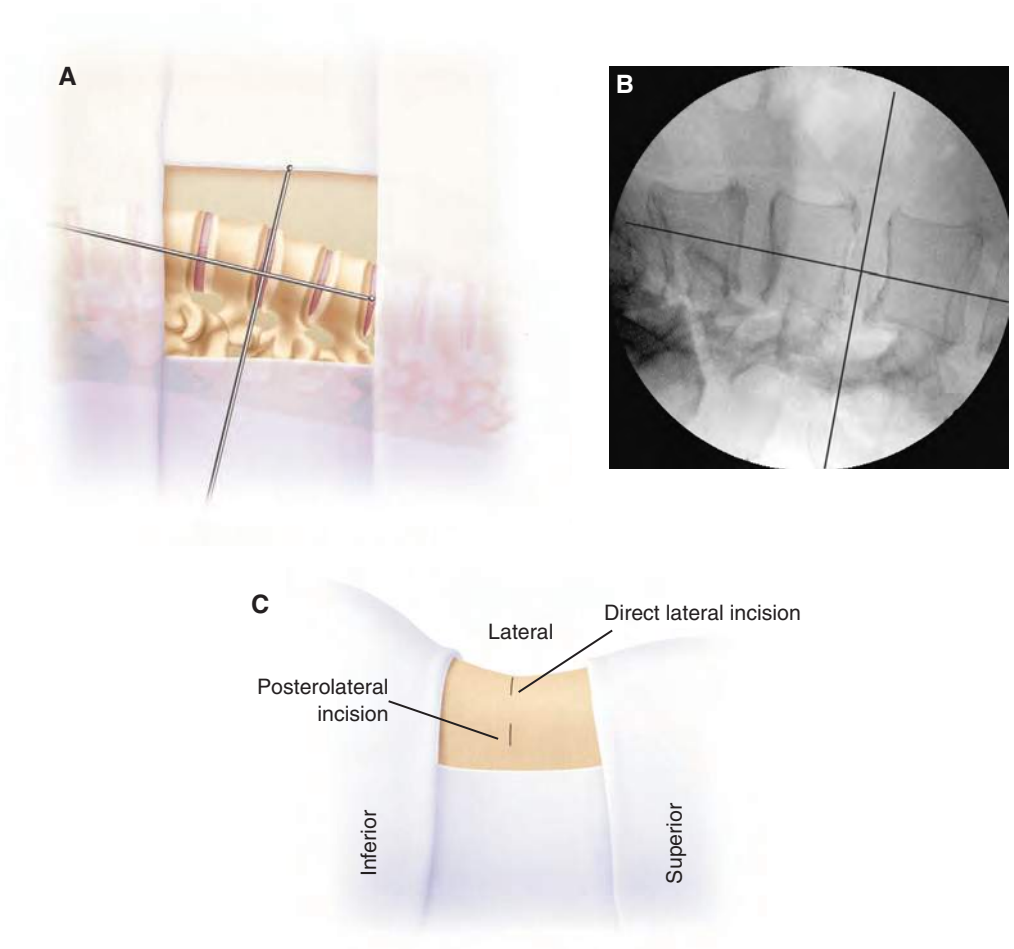


FIG. 8-4 **A** and **B,** Using lateral fluoroscopy, the disc space is localized by crossing two K-Wires over the pathologic level and centering them over the indicated disc space. **C,** A mark on the skin is made at the intersection of the K-Wires to serve as the location of the skin incision for the operative corridor (direct lateral incision). Another mark is made between the ilium and the rib cage (posterolateral incision), indicating the access to the retroperitoneal space.

Step Two: Retroperitoneal Access

Through the posterolateral incision, the subcutaneous tissue layers are dissected using alternating blunt scissors and finger dissection (Fig. 8-5, *A*). The blunt scissors are used to carefully spread the muscle fibers, and subsequent finger advancement allows the surgeon to determine whether resistance by the muscle tissue is present. Typically, a loss of resistance by the muscle tissue indicates that the retroperitoneal space has been reached. Care should be taken to avoid abrupt advancement, which could cause perforation of the peritoneum. Once the index finger is inside the retroperitoneal space, a gentle sweeping motion is used to release the peritoneum anteriorly and to ensure that the abdominal contents have

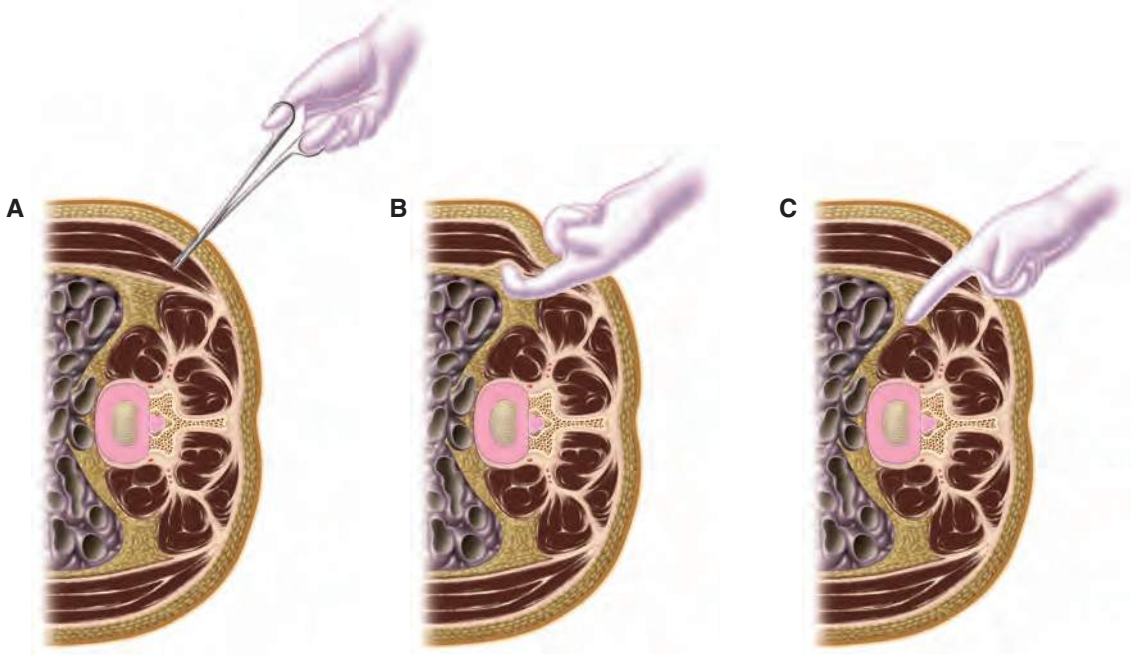


FIG. 8-5 **A,** The subcutaneous tissue layers are dissected using blunt scissors and alternating them with finger dissection. **B,** Using a gentle sweeping motion, the index finger releases the peritoneum anteriorly and ensures that the abdominal contents have fallen forward. **C,** After the peritoneum is released, the finger palpates the psoas muscle, or anterior tip of the transverse process, for landmark identification.

fallen forward, creating a safe space through which the Dilators and Retractor will pass (Fig. 8-5, *B*). When the peritoneum is released, the finger is used to palpate the psoas muscle or anterior tip of the transverse process (Fig. 8-5, *C*) for landmark identification.

POSTEROLATERAL INCISION

Once the psoas muscle is located through the posterolateral incision, the index finger is swept up to the inside abdominal wall, underneath the direct lateral skin mark (Fig. 8-6, *A*). This step ensures that a safe pathway is present between the abdominal wall and the psoas muscle. An incision is made at this location (Fig. 8-6, *B*), and the initial NeuroVision Dilator (black) is introduced (Fig. 8-6, *C*). The Dilator is passed through the oblique muscle layers to meet the index finger that is just inside the retroperitoneal space. This finger is used to guide the initial Dilator safely past the peritoneum, down to the surface of the psoas muscle (Fig. 8-6, *D*).

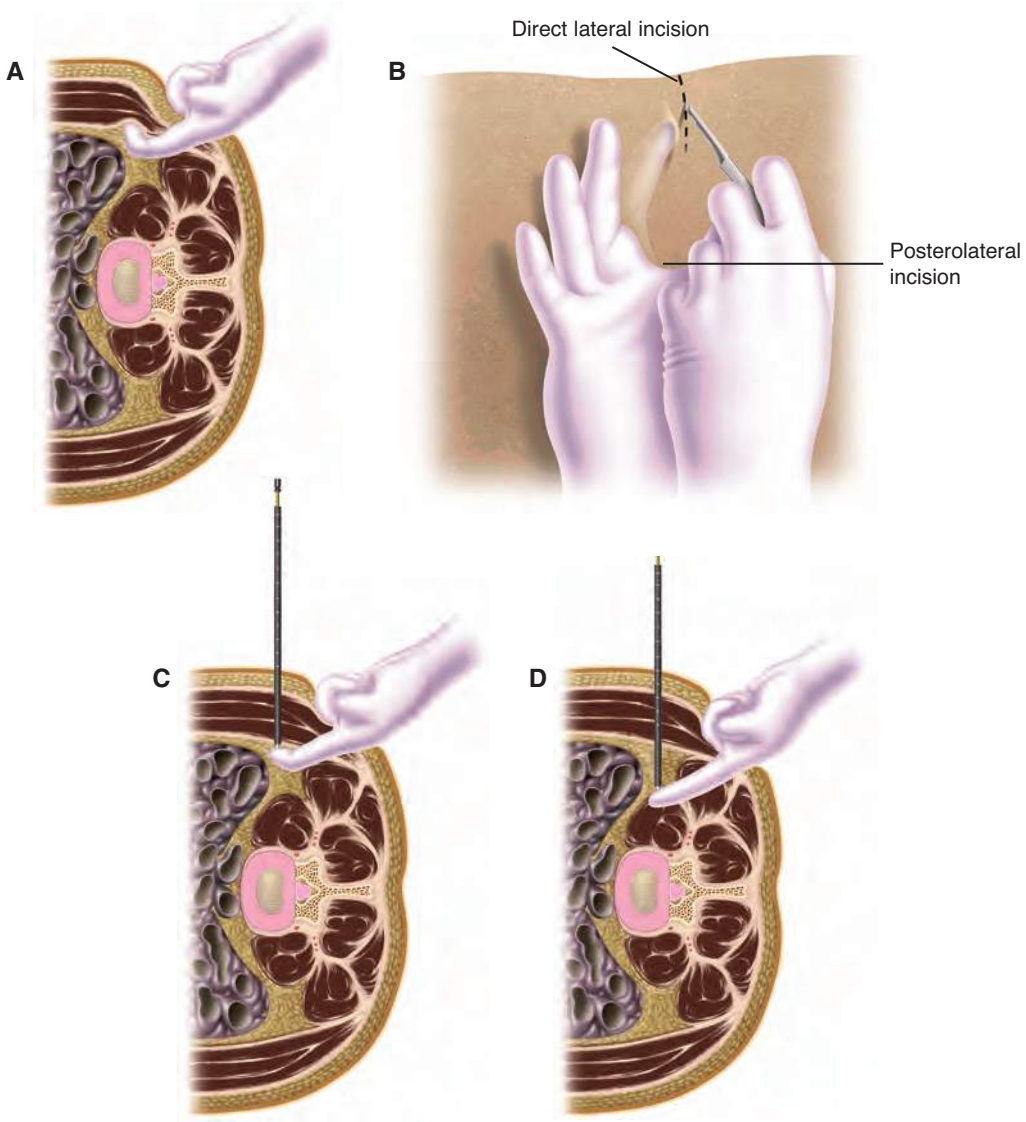


FIG. 8-6 **A,** After the psoas muscle is located, the index finger sweeps to the inside abdominal wall underneath the direct lateral skin mark to ensure a safe pathway between the abdominal wall and the psoas muscle. **B,** An incision is made at this location. **C,** The initial NeuroVision Dilator (black) is introduced and meets the index finger just inside the retroperitoneal space. **D,** The finger guides the Dilator to the surface of the psoas muscle.

Step Three: Transpsoas Approach

When the NeuroVision Dilator contacts the surface of the psoas muscle, the location is verified with a lateral fluoroscopic image. The ideal location is approximately at the center (or just posterior to the center) of the disc space (Fig. 8-7). NeuroVision EMG stimulation is connected to the Dilator. The Large NeuroVision Dynamic Stimulation Clip is attached to the proximal end of the initial Dilator, and the system is activated in Detection mode (Fig. 8-8, *A* and *B*). The fibers of the psoas muscle are split using blunt dissection with the initial

Dilator, which is slowly advanced while NeuroVision remains active in the Detection mode (Fig. 8-8, *C*). As the Dilator is advanced through the psoas, NeuroVision's dynamically stimulated discrete EMG guidance is used to identify and avoid the nerves of the lumbar plexus (Fig. 8-8, *D*). A direct lateral trajectory, targeting approximately the middle of the disc, minimizes the chance of encountering a nerve and ensures that the anterior vessels remain well anterior to the access corridor. If the Dilator approaches too close to a nerve, it is slowly rotated 360 degrees to determine the location of the nerve. A line on the proximal end of the Dilator corresponds to an electrode on the side of the distal tip. NeuroVision indicates a higher stimulation threshold value when the electrode faces away from the nerve. In this case, the Dilator is removed from the psoas, moved slightly in this direction, and a new path through the psoas muscle is attempted (see Fig. 8-7). The NeuroVision Twitch Test is used to determine the level of muscle relaxants in the patient (Fig. 8-8, *E*).

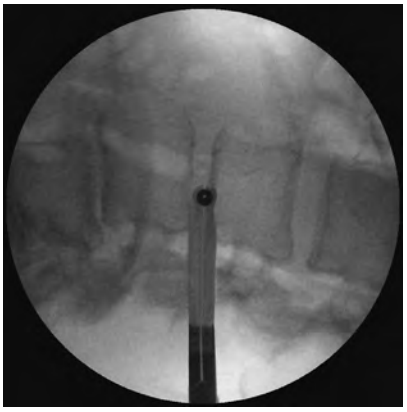


FIG. 8-7 After the initial NeuroVision Dilator reaches the surface of the psoas muscle, the location is verified with a lateral fluoroscopic image. The ideal location is approximately at the center (or just posterior to the center) of the disc space.

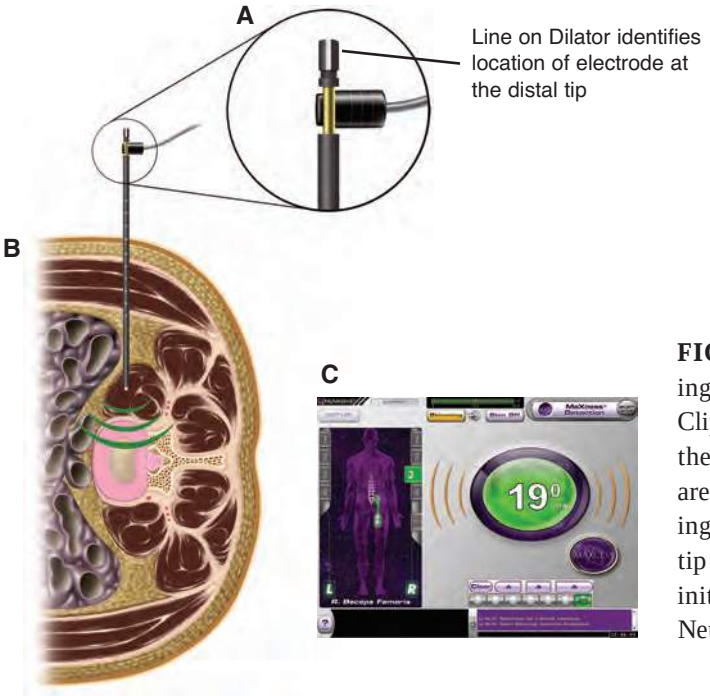


FIG. 8-8 NeuroVision EMG Monitoring. **A,** The Large Dynamic Stimulation Clip is attached to the proximal end of the NeuroVision Dilator. **B,** The Dilators are insulated to minimize current shunting, and an isolated electrode at the distal tip acts as the stimulation source. **C,** The initial Dilator is slowly advanced while NeuroVision is active in Detection mode.

FIG. 8-8, cont'd **D,** The descending nerves of the lumbar plexus tend to lie in the posterior one third of the psoas muscle. The NeuroVision System assists with safe passage past these nerves and/or confirmation of their posterior location via evoked EMG monitoring. In Detection mode, the NeuroVision System continuously searches for the stimulus threshold that elicits an EMG response on the myotomes being monitored and audibly and visually reports the thresholds. As the Dilator is advanced through the psoas muscle, the stimulus necessary to elicit an EMG response varies with the distance from the nerve. For example, as the stimulus source moves closer to the nerve, less stimulus intensity is required to elicit a response, resulting in a lower threshold, which provides an indication of the relative proximity of the Dilator to the nerves. Literature reports suggest that stimulation thresholds of less than 5 mA may indicate direct nerve stimulation,[1-3] and other experience has suggested that threshold values greater than 10 mA indicate a distance that allows both continued nerve safety and ample working space.[4] **E,** The Twitch Test can be performed either in peripheral stimulation mode (the stimulation is directed through an electrode at the popliteal fossa) or direct stimulation mode (the stimulation is directed through instruments in the surgical wound). The system stimulates with four pulses and displays the results of each twitch as a percentage of the first one. A fourth twitch with at least 75% of the strength of the first is required to ensure accurately quantifiable EMG readings.

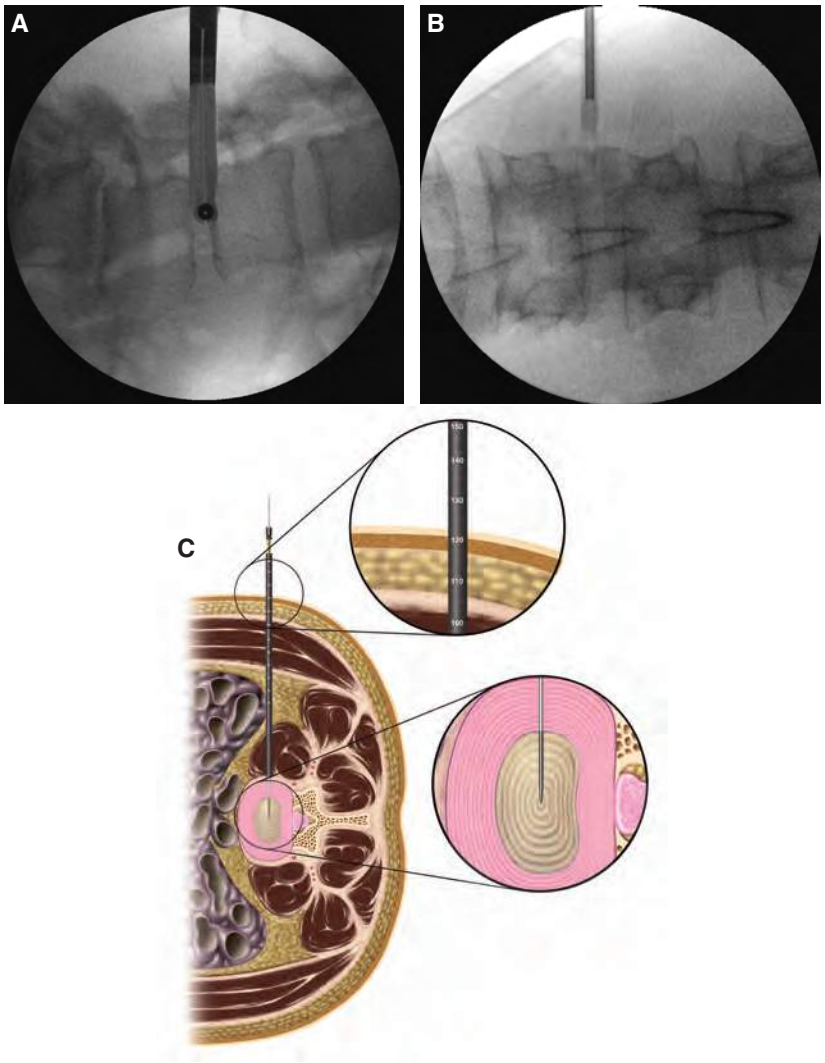


FIG. 8-9 **A,** After the initial Dilator is on the disc, a lateral radiograph confirms that the Dilator is approximately centered on, and parallel with, the disc. **B,** A cross-table anteroposterior image confirms that the Dilator is in the plane of, and flush with, the disc space. **C,** A K-Wire is introduced about halfway into the disc space to secure the position.

Once the initial Dilator is on the disc, fluoroscopy is used to confirm its position. A lateral image should confirm that the Dilator is approximately centered on and parallel with the disc (Fig. 8-9, *A*). If the Dilator is not at the optimal position, NeuroVision's Detection mode may be reactivated and the Dilator's position adjusted. A cross-table anteroposterior image should confirm that the Dilator is in the plane of and flush with the disc space (Fig. 8-9, *B*). After confirming the position, a K-Wire is introduced approximately halfway into the disc space to secure the position (Fig. 8-9, *C*). Subsequent dilation and muscle-splitting retraction are used to establish the operative corridor. Depth markings on the Dilator indi-

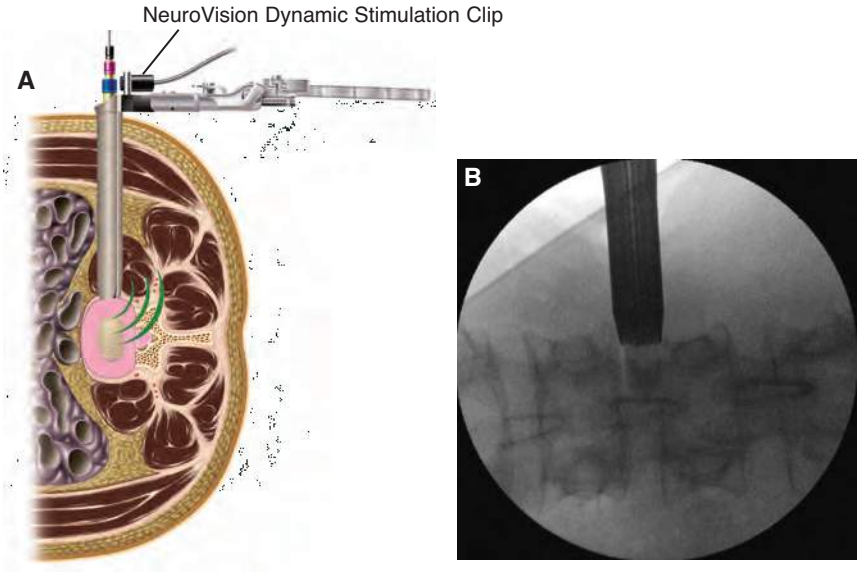


FIG. 8-10 **A,** The NeuroVision Dynamic Stimulation Clip is attached to the post on top of the center Blade to stimulate an electrode on the distal end of the Blade. **B,** A cross-table anteroposterior fluoroscopic image is used to confirm the correct position of the Access Driver Blades on the spine and to ensure that the Blades are parallel with the disc space.

cate the appropriate length of the Blade to be loaded onto to the MaXcess Access Driver. The Blades are tightened via set screws.

The next two NeuroVision Dilators (magenta and blue) are subsequently introduced over the initial Dilator using a twisting motion. As with the previous Dilator, NeuroVision's dynamically stimulated EMG guidance is used to minimize potential nerve contact. The Access Driver is introduced over the third Dilator, with the handles pointing posteriorly. The NeuroVision Dynamic Stimulation Clip may be attached to the post on top of the center Blade to stimulate an electrode on the distal end of the Blade (Fig. 8-10, *A*). Cross-table anteroposterior fluoroscopy is used to confirm that the position of the Access Driver Blades on the spine is correct and that the Blades are parallel with the disc space (Fig. 8-10, *B*).

The MaXcess Retractor is stabilized to the table by attaching an Articulating Arm from the bedrail to the Access Driver (Fig. 8-11, *A*). The Access Driver allows two different points of attachment: (1) attachment on the center Blade, which ensures that the exposure opens only anteriorly from that position, avoiding pressure on the nerves posterior to the center Blade and (2) attachment closer to the handles of the Retractor, which results in the center Blade moving posteriorly when opened and having more posterior exposure. However, in this scenario, extra care must be taken to avoid compression of neural elements against the transverse processes behind the center Blade.

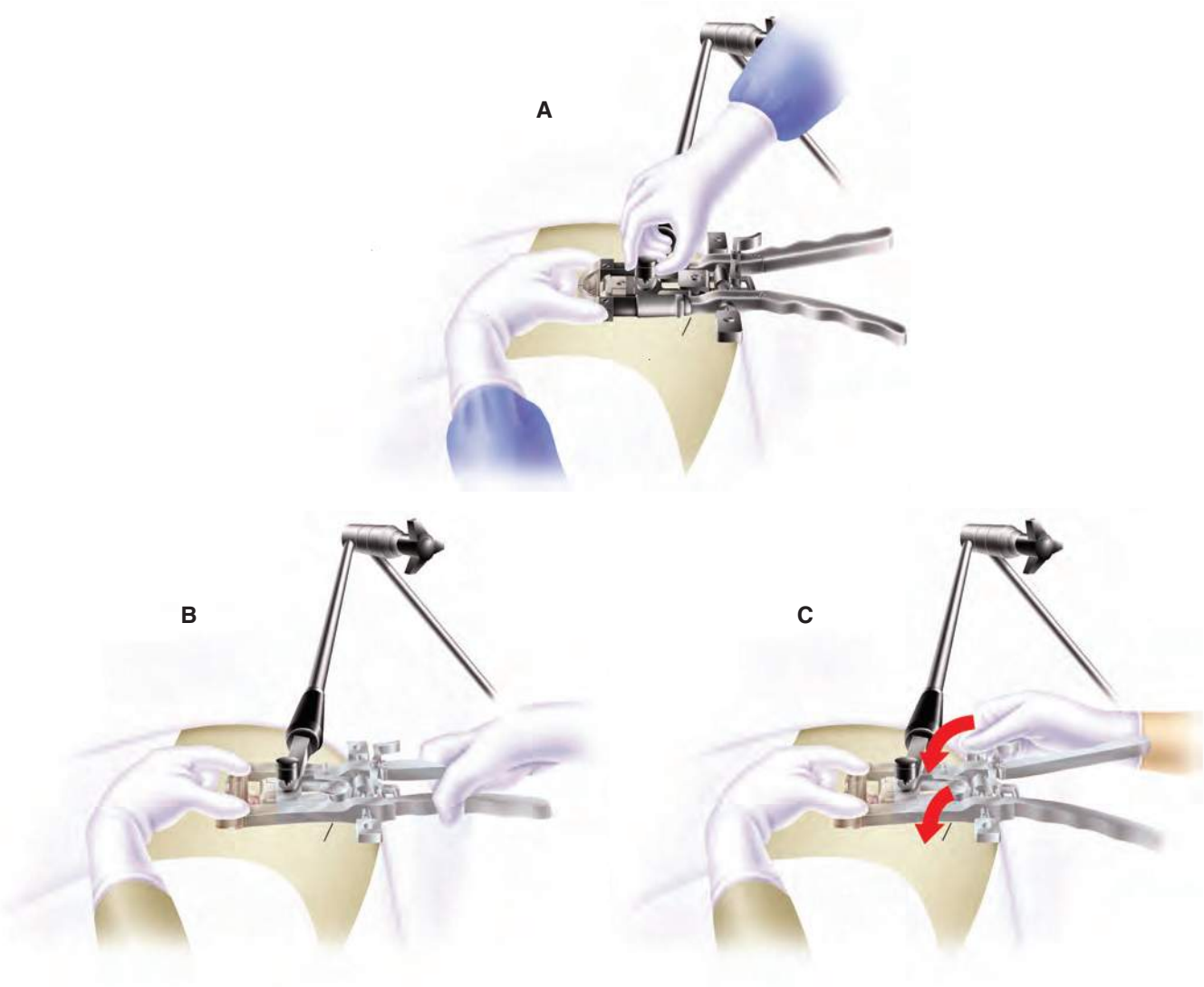


FIG. 8-11 **A,** The MaXcess Retractor is stabilized to the table by attaching an Articulating Arm from the bedrail to the Access Driver. **B,** The Retractor is gently opened by squeezing the handles on the Access Driver until the Blades are expanded in a superior/inferior direction by approximately three "clicks." **C,** Anterior/posterior exposure is achieved by turning the knobs on the sides of the Access Driver forward.

While holding the Access Driver in position and using downward pressure, the Retractor is gently opened by squeezing the handles on the Access Driver so that the Blades are expanded approximately three "clicks" in a superior/inferior direction (Fig. 8-11, *B*). Anterior/posterior exposure is achieved by turning the knobs on the sides of the Access Driver forward (Fig. 8-11, *C*).

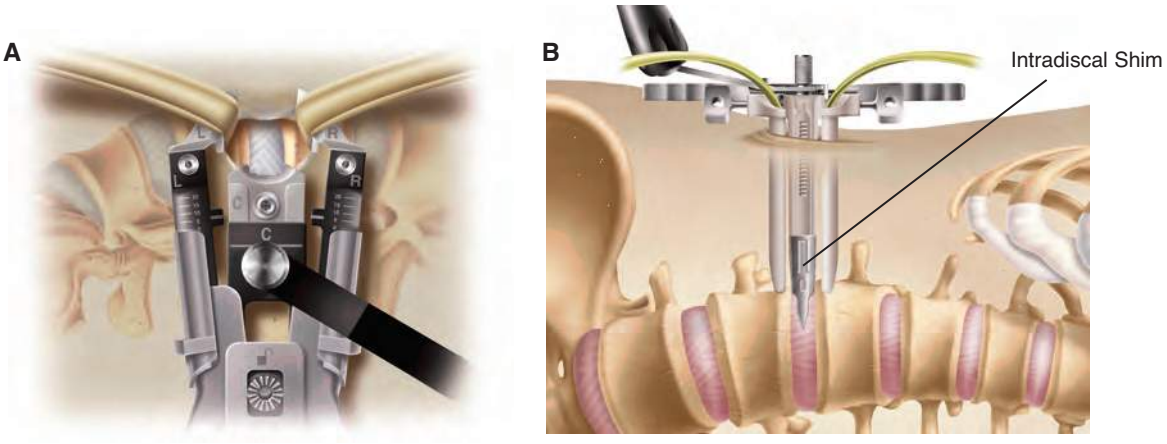


FIG. 8-12 **A,** Direct, illuminated visualization is achieved by passing the two ends of the bifurcated Light Cable about halfway down the left and right Blades of the Access Driver. The two ends of the Light Cable are bent flush to the surface of the Access Driver. **B,** An Intradiscal Shim may be placed into the disc space to further stabilize the Retractor to the patient.

Direct, illuminated visualization is achieved by passing the two ends of the bifurcated Light Cable about halfway down the left and right Blades of the Access Driver. The two ends of the Light Cable are bent flush to the surface of the Access Driver (Fig. 8-12, *A*). The proper anterior/posterior position should be verified using lateral fluoroscopy. Any residual tissue at the bottom of the exposure should be thoroughly explored. The NeuroVision Pedicle Probe is used to confirm that nerves are not within the exposure. Shims are available in various sizes to either effectively widen or lengthen the Blades to keep tissue out of the exposure. An Intradiscal Shim may be placed into the disc space to further stabilize the Retractor to the patient (Fig. 8-12, *B*).

The XLIF instrument set contains tools such as Penfields, Nerve Retractors, and Psoas Retractors, which can be used to tuck residual tissue behind the Shims. If electrocautery is necessary for further visualization of the disc, bipolar—not monopolar—cautery should be used sparingly to avoid thermal injury to the nearby nerves and unnecessary trauma to the psoas muscle.

The distal part of the exposure can be widened without enlarging the skin incision by rotating either one or both of the Blades using the Blade Rotation Wrenches or Blade Rotation Spreader. This may be helpful to preferentially adjust the exposure in either direction (for example, inferiorly at L4-5 under the iliac crest) to gain optimal access to the disc space, but care should be taken to avoid expanding the Blades to the midvertebral body to minimize psoas trauma and the risk of segmental vessel injury. Exposure need only be as wide as the disc space. Blade rotation locks automatically slide toward the Blades on the left and right arm of the Access Driver to secure the Blades' position.

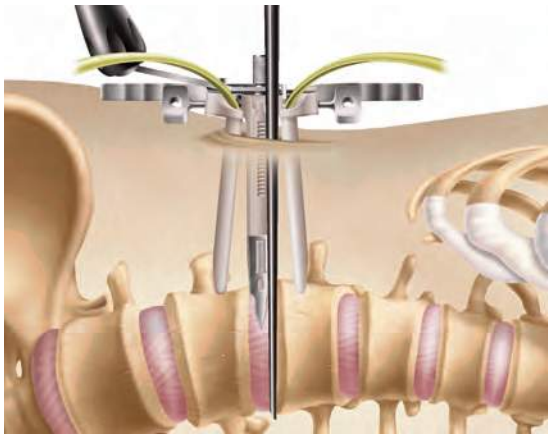


FIG. 8-13 Contralateral anular release is performed by passing the Cobb Elevator along both endplates and completely through the contralateral anulus.

Step Four: Disc Space Preparation

With the operative corridor in place and disc exposure achieved, the disc space can be prepared in a conventional manner using intradiscal instruments, such as the Rongeurs, Curettes, and Rasps found in the XLIF instrument set. The anulotomy must be at least 18 mm long (anterior to posterior) to accommodate the XLIF implant. A number of XLIF instruments can be used to measure this space and thoroughly evacuate the disc and to prepare the endplates for fusion. Contralateral anular release is critical to the parallel distraction of the disc space and proper coronal alignment. This release can safely be performed by passing the Cobb Elevator along both endplates and completely through the contralateral anulus (Fig. 8-13). The contralateral anular release ensures symmetrical disc space preparation, parallel disc distraction, and the ability to place a large implant on the dense ring apophysis bilaterally.

Step Five: Implant Sizing and Placement

One of the biggest advantages of a lateral approach to the spine is the ability to place a large implant that makes use of the densest areas of endplate support. For this reason, the implant length should allow the lateral margins of the implant to span the ring apophysis, aligning with the lateral borders of the endplate on an anteroposterior image. The implant height should allow adequate disc height restoration without excessive strain on the endplates or anterior longitudinal ligament. Sagittal alignment can be restored through the anterior

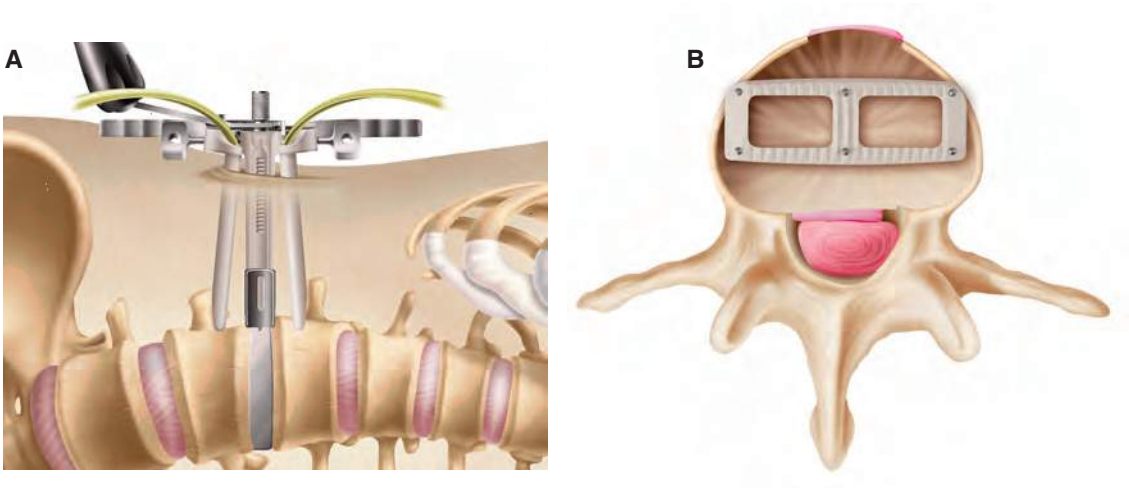


FIG. 8-14 **A** and **B,** The implant is ideally centered across the disc space from a medial/lateral perspective and placed between the anterior third and middle third of the disc space from an anterior/posterior perspective.

placement of a nonlordotic implant or through a more central placement of a 10-degree lordotic implant. Indirect decompression can be expected from corrections in the disc height, sagittal and coronal alignment, and anterior and lateral listheses.

The XLIF Distractor and Sizers are used to distract the disc space and to gauge the appropriately sized Trial, which is gently impacted into the disc space under anteroposterior fluoroscopy until it is centered. The proper anterior/posterior position should be verified using lateral fluoroscopy. The corresponding implant, filled with graft material, is gently impacted into the disc space under anteroposterior fluoroscopy and NeuroVision Free-Run EMG monitoring. Ideally, the implant is centered across the disc space from a medial/lateral perspective (Fig. 8-14, *A*) and placed between the anterior third and middle third of the disc space from an anterior/posterior perspective (Fig. 8-14, *B*).

LATERAL PLATING: XLP™

Supplemental instrumentation may include lateral or posterior fixation systems. If lateral plating (XLP, NuVasive, Inc.) is chosen, the pilot hole is prepared and the Bolt is inserted through XLP Guides (NuVasive, Inc.). A Guide of the appropriate length is introduced through the XLIF exposure and centered over the disc space. With the Guide properly positioned, the spikes are inserted into both vertebral bodies to secure them in place. Several instruments are available in the XLP set to create pilot holes, including Taps, Drills, and Awls. The selected instruments are inserted through the XLP Guide, and a pilot hole is created to the desired depth and trajectory (Fig. 8-15, *A*).

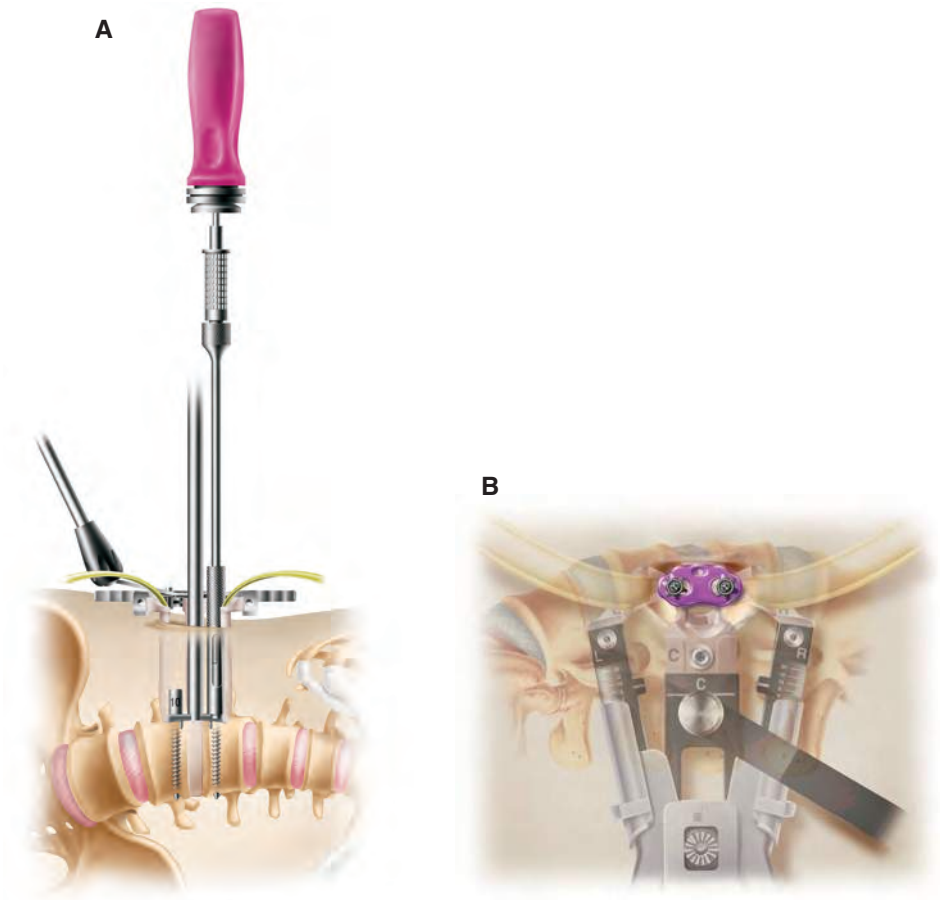


FIG. 8-15 **A,** A pilot hole is created to the desired depth and trajectory. **B,** The Plate is fully seated, and Lock Nuts are inserted onto both Bolts and tightened.

After the pilot hole is prepared, a Bolt is introduced through the Guide barrel and inserted to depth. The Bolt insertion procedure is repeated on the adjacent level. With the Bolts in place, the Plate is inserted over both Bolts, ensuring that the heads are properly exposed above the Plate for Lock Nut insertion. The Plate is confirmed to be fully seated by direct visualization, and Lock Nuts are inserted onto both Bolts and tightened (Fig. 8-15, *B*).

Closure

After the procedure is completed, the Access Driver is removed, and direct visualization is used to verify the absence of significant bleeding in the disc space or psoas muscle. The skin is closed using standard subcuticular suture. Supplemental posterior instrumentation is added as warranted.

Postoperative Management and Expectations

Patients should be encouraged to walk within hours of the surgery to aid their recovery and muscle function. Postoperative pain from the lateral incision tends to be minimal, and, depending on the supplemental procedures performed and any preexisting comorbidities, patients may be discharged after only an overnight hospital stay.

Postoperative tenderness with hip flexion on the operative side is common and resolves spontaneously within the first 2 weeks after surgery as the psoas muscle heals. Less commonly, sensory disturbances in the operative side leg may occur; these can also be expected to resolve within the first weeks after surgery. Painful dysesthesias are rare, and most cases resolve within 6 weeks. Motor disturbances in the operative side leg are exceedingly rare, but possible. In these situations, it is recommended to obtain a postoperative CT scan to rule out a psoas hematoma. If a hematoma is found, draining it improves symptoms. Continued mobilization, physical therapy, and treatment with gabapentin (Neurontin), pregabalin (Lyrica), levetiracetam (Keppra), or other anticonvulsant/nerve stabilizing agents are recommended. To date, there have been no known cases of permanent motor deficit.

All of these side effects can be minimized through gentle muscle manipulation and care during the approach, with the stringent use of EMG guidance and careful nerve retraction when necessary.

Technical Tips

- Placing the patient in a true lateral position is critical to the safety and reproducibility of lateral access surgery. The time spent properly positioning the patient facilitates the ease with which the procedure then proceeds.
- Careful attention to properly positioning the patient over the break in the table and flexing the table ensures access to the L4-5 disc space in all cases by moving the pelvis away from the spine.
- Finger dissection and guidance of the initial Dilator through the retroperitoneal space adds safety and reproducibility by preventing visceral injury.
- Dynamic EMG stimulation with discrete threshold monitoring allows the directional identification of nerves and their avoidance during the transpsoas approach.
- Disc space preparation must include the contralateral release of the anulus to ensure parallel distraction, the placement of a large implant across the ring apophysis, and alignment correction.

REFERENCES

1. Calancie B, Madsen P, Lebwohl N. Stimulus-evoked EMG monitoring during transpedicular lumbosacral spine instrumentation: initial clinical results. Spine 19:2780-2786, 1994.
2. Holland NR, Lukaczyk TA, Riley LH, et al. Higher electrical stimulus intensities are required to activate chronically compressed nerve roots. Spine 23:224-227, 1998.
3. Maguire J, Wallace S, Madiga R, et al. Evaluation of intrapedicular screw position using intraoperative evoked electromyography. Spine 20:1068-1074, 1995.
4. Peloza J. Validation of neurophysiological monitoring of posterolateral approach to the spine via discogram procedure. Poster presented at the Ninth International Meeting on Advanced Spine Techniques, Montreux, Switzerland, May 2002.