Spine

Extreme lateral interbody fusion - XLIF

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ABSTRACT

Anterior and posterior approaches for lumbar interbody fusion can be associated with a number of serious complications. Interest in minimally invasive approaches for interbody fusion has increased in recent years, with the goal of decreasing complications and patient morbidity. The goal of minimally invasive spine surgery is to decrease operative time, decrease blood loss, improve cosmesis, shorter hospital stays and faster recovery time. Extreme lateral interbody fusion (XLIF) is a relatively new technique whereby access to the disc space is achieved through a minimally invasive lateral, retroperitoneal, trans-psoas approach. The nerves of the lumbar plexus reside within the psoas, and the technique is dependent upon real-time electromyographic monitoring. The purpose of this review is to present an overview of the XLIF technique, with particular attention paid to indications, advantages, biomechanics, and early clinical and radiographic results.

Keywords

XLIF, lateral approach, interbody fusion, minimally invasive, spinal deformity

INTRODUCTION

Interbody fusion involves the placement of a structural implant (spacer, allograft, or cage) within the disc space after a complete discectomy and preparation of endplates. Lumbar interbody fusion, as originally described by Capener in the 1930s, used an anterior approach to the lumbar spine.[1] Cloward[2] introduced posterior lumbar interbody fusion (PLIF) in 1945 for the treatment of lumbar disc herniations. Transforaminal lumbar interbody fusion (TLIF) was refined and popularized by Harms and Jeszensky[3] and uses a unilateral posterior approach to the anterior column. More recently Pimenta popularized the lateral approach to interbody fusion, or extreme lateral interbody fusion (XLIF).[4] Nowadays, various types of bone grafts and bone graft extenders also are available that can be placed within and around the implant to help promote fusion.

Interbody spine fusion has several theoretical advantages over traditional posterolateral fusion. Interbody fusion allows for a much larger area for fusion than is available with posterolateral fusion. Because the graft is placed anterior to the instantaneous axis of rotation, it is exposed to compressive rather than tensile forces, which is a more favorable environment for bone fusion. Pseudarthrosis rates after posterolateral fusion range from 14–21%.[5,6] Fusion rates after instrumented interbody fusions vary depending on technique, interbody implant, graft material and the use of supplemental instrumentation. In general, reported fusion rates after interbody fusions are considerably higher than those seen after posterolateral fusions.[7–11]

Compared to traditional posterolateral fusion, interbody fusion also is advantageous from a biomechanical perspective. Without interbody support, normal physiologic loads can exceed the bending strength and stiffness of posterior pedicle screw constructs.[12] Anterior column reconstruction with structural interbody grafts provides immediate segmental stability, thereby unloading the posterior segmental instrumentation and increasing the endurance limit of the construct.[13,14]

The indications for lumbar interbody fusion are essentially the same as those for traditional posterolateral fusion and include degenerative disc disease, trauma, tumor, infection, deformity and instability. More recently, interbody fusion has been used in discogenic low-back pain; however, this is the most controversial indication for lumbar interbody fusion.

The goals of interbody fusion are to attain a solid fusion and to restore disc space height, foraminal dimensions, and coronal and sagittal balance. Most commonly, interbody

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fusions are performed through either an anterior or posterior approach to the lumbar spine. Both may be associated with significant approach-related complications. Complications of posterior approaches (PLIF, TLIF) may include pseudarthrosis, graft dislodgement, and neurologic injury.[15] The extensive muscle stripping and denervation associated with the traditional posterior midline approach also can lead to atrophy, chronic dysfunction of the lumbar paraspinal musculature and failed back syndrome.[16–19] Anterior lumbar interbody fusion (ALIF) requires mobilization of the abdominal contents, and most spine surgeons today require the assistance of a general or vascular access surgeon. Even so, complication rates of ALIF range from 2.8–80% and most frequently involve vascular injury, somatic neurologic injury, deep venous thrombosis and sexual dysfunction.[20–28] Less commonly, ureteral injury, bowel injury, lumbar sympathetic dysfunction, wound dehiscence and hernias have been reported.[20,23,29] The complication rate increases significantly if the anterior approach is used for revision surgery.[30]

Recently, more attention has been given to alternative, less invasive techniques that minimize approach-related complications and patient morbidity. XLIF is one relatively new technique that appears to accomplish this goal. The purpose of this review is to give a general overview of XLIF. Particular attention is given to indications, surgical technique, advantages, and potential complications of this approach in the surgical treatment of spinal disorders.

MINIMALLY INVASIVE APPROACHES TO LUMBAR INTERBODY FUSION

Minimally invasive spine (MIS) surgery has been increasing in popularity in recent years. With improved instrumentation and retractor systems, spine surgeons can now perform a vast array of procedures previously only possible through large, open approaches, using MIS techniques. In general, the potential advantages of MIS techniques include smaller incisions, less damage to soft-tissue structures, improved cosmesis, decreased blood loss, shorter hospital stays, less postoperative pain and faster recovery time.

MIS techniques potentially offer additional advantages specific to interbody fusion. MIS TLIF for example uses a unilateral paramedian, muscle-splitting approach to the facet of interest. The entire procedure is performed through a tubular retractor system. By avoiding the extensive muscle stripping required with the traditional posterior midline approach, the hope is to lower the incidence of chronic pain and fatigue symptoms, or "fusion disease." Further, by preserving the integrity of the posterior soft-tissue envelope, the risk of adjacent segment degeneration and junctional disease should, theoretically, be lower. A short-term outcome study available in the literature on minimally invasive approaches to interbody fusion demonstrated good intermediate-term (6–12 months) results in 85% of patients after MIS TLIF.[31]

EXTREME LATERAL INTERBODY FUSION (XLIF)

The lateral approach to interbody fusion, or XLIF has been popularized by Osgur *et al.*[4] It is a relatively new technique whereby access to the disc space is achieved through a minimally disruptive lateral, retroperitoneal, trans-psoas approach to the spine. Blunt dissection of the psoas major muscle is achieved with the use of a series of dilators. The nerves of the lumbar plexus lie within the substance of the psoas and real-time electromyographic (EMG) monitoring is performed to direct safe passage through this corridor.

The lateral approach to interbody fusion has many advantages over anterior and posterior approaches. The lateral approach avoids the risks of anterior surgery. Mobilization of the abdominal contents and great vessels is not required. Injury to the hypogastric sympathetic plexus and injury to the gastrointestional and genitourinary systems are similarly avoided. Accordingly, there is usually no need for an approach surgeon. The lateral approach also avoids all of the posterior approach-related complications seen with open TLIF and PLIF. Extensive muscle stripping and denervation are avoided. Retraction of the neural elements is not required, avoiding the potential for associated neurologic and dural related complications.

In terms of technical difficulty, the lateral approach is relatively simple to perform, with a rather gradual learning curve. The lateral approach involves minimal soft-tissue disruption and is associated with minimal blood loss, decreased operative time, less postoperative pain, shorter hospital stays and quicker recovery and return to work.

BIOMECHANICS OF LATERAL INTERBODY FUSION

There are several important issues related to the biomechanics of interbody fusion that deserve mention. Numerous biomechanical studies have demonstrated that stand-alone ALIF does not provide adequate segmental stability, necessitating the use of supplemental fixation.[32–34] The addition of an anterior plate, posterior translaminar facet screws, or posterior transpedicular screws imparts sufficient immediate stability to anterior lumbar interbody constructs.[35,36]

Two recent studies evaluated the biomechanics of interbody reconstruction after a lateral approach.[37,38] Kim *et al.*[37] showed that both anterior and lateral discectomy cause segmental instability. Stand-alone anterior or lateral interbody reconstruction with femoral ring allograft restored segmental stability to that of the intact spine. The addition of a lateral plate to the lateral interbody construct resulted in a significant increase in segmental stability compared with the stand-alone construct. The addition of posterior pedicle screw instrumentation to the anterior interbody construct also resulted in a significant increase in segmental stability compared with both the stand-alone anterior interbody construct and the lateral interbody/plate construct. In another cadaver study, Bess *et al.*[38] demonstrated that stand-alone XLIF constructs and various instrumented XLIF constructs (lateral plate, unilateral pedicle screws, bilateral pedicle screws) all led to increased stability when compared with the intact spine.

The improved immediate stability seen after lateral interbody reconstruction of the cadaveric spine has been attributed to a number of causes. Tencer *et al.*[39] has demonstrated the destabilizing effect of sectioning the anterior longitudinal ligament (ALL) in calf and human cadaveric spines. The lateral approach does not violate the ALL as occurs during anterior discectomy and interbody fusion. Preservation of this structure likely has an important role in maintaining segmental stability after lateral discectomy and interbody reconstruction.

There are no published studies directly comparing the stability of lateral interbody constructs to posterior interbody constructs using the PLIF or TLIF technique. However, the destabilizing effect of unilateral and bilateral hemifactectomy performed during TLIF and PLIF is well known.[40–42] The lateral approach does not violate the posterior osseoligamentous ring.

The lateral approach allows for a large interbody implant to be placed. Larger implants more effectively restore foraminal dimensions, as well as, sagittal and coronal alignments. Ideally, the implant should span the entire disc space from medial to lateral, and rest on the peripheral portion of the endplate, or the ring apophysis. The peripheral portion of the endplate is stronger than the central portion. Therefore, larger implants also enable endplate stresses to be distributed over a larger surface area. Larger surface areas equate to lower stresses at the bone-implant interface. Interbody implants placed though a lateral approach can therefore provide greater resistance to implant subsidence, which is a major complication associated with the ALIF technique.[43]

PATIENT SELECTION AND SURGICAL INDICATIONS

In his initial description of the XLIF procedure, Osgur *et al.*[4] used the technique in patients with degenerative disc disease and axial low back pain. Candidates for the procedure were essentially those who would otherwise be considered for ALIF. Patients were not considered candidates for the procedure if they demonstrated severe central canal stenosis, significant scoliotic deformity, or moderate to severe spondylolisthesis.

The indications for the XLIF procedure have since been expanded to include patients with a variety of spinal pathologies. Exposure of the L5-S1 disc space is limited by the iliac crests and so the lateral approach may only be used in situations requiring anterior column stabilization above L5. The XLIF approach can be used to treat patients with degenerative disc disease, complex spinal deformity and spondylolisthesis. Thoracic or lumbar corpectomy and lumbar total disc replacement also can be accomplished through the lateral approach. Patients requiring revision after either prior failed fusion surgery (pseudarthrosis, adjacent level disease) or revision of failed total disc replacement surgery are all candidates for the lateral approach. Finally, the lateral approach also has been used as an alternative approach to the thoracic spine. Thoracic disectomy and corpectomy can be performed with minimal variation in the surgical technique. Accordingly, thoracic disc herniations, thoracolumbar trauma, tumors and infections also may be treated through a lateral approach.

SURGICAL TECHNIQUE FOR INTERBODY FUSION

The XLIF procedure consists of five key steps: 1) patient positioning; 2) retroperitoneal access; 3) transpsoas access and disc exposure; 4) discectomy and disc space preparation; and 5) interbody implant sizing and placement. Compulsive attention to detail is essential to ensure patient safety. Strict adherence to these guidelines will achieve reproducible results and maximize the potential for success.

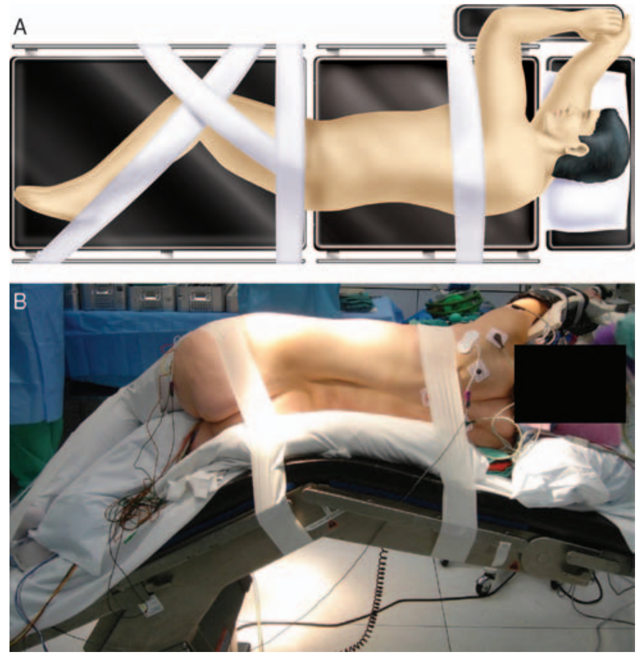

FIGURE 1. (A) The patient is placed in the lateral decubitus position with the greater trochanter over the table break, and secured in place with tape. (B) The table is flexed to increase the distance between the ribs and the iliac crest. (A reproduced with permission from NuVasive, San Diego, CA).

Patient Positioning

The patient is placed on a radiolucent operating table capable of flexing near its midportion. After endotracheal intubation, general anesthesia is administered and lines are placed. The patient is placed in the true lateral decubitus position with the greater trochanter positioned directly over the table break. An axillary roll is placed, and all bony prominences are padded. The patient is secured to the operating room table using tape, and the table is flexed to increase the distance between the ribs and the iliac crest (Figure 1 A and B). Fluoroscopy is used to ensure that good, unobstructed images of the disc space of interest have been obtained on both the crosstable anteroposterior (AP) and lateral views. The table is rotated as necessary to provide true AP and lateral images of the disc space. The skin is prepared and draping is performed in the usual manner.

Retroperitoneal Access

The lateral approach uses a one or a two-incision technique, the latter of which is the authors' preferred method. The two-incision approach includes a direct lateral incision and a posterolateral incision. The direct lateral incision is the working portal. It is centered over the target disc space, as

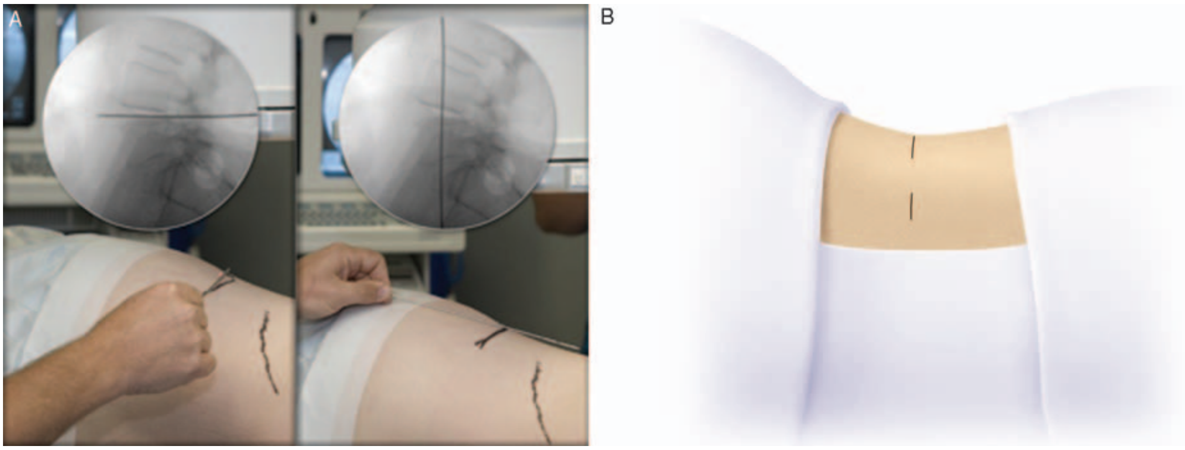

FIGURE 2. (A) A lateral fluoroscopic image is obtained to ensure that the direct lateral skin incision is centered over the target disc space. The posterolateral incision is located four fingerbreadths posterior to the direct lateral incision. (B) The skin is marked appropriately. (B reproduced with permission from NuVasive, San Diego, CA).

confirmed on the lateral fluoroscopic image. The skin is marked appropriately (Figure 2 A and B). If two levels are to be treated, then the direct lateral skin incision is made halfway between the two target levels. For multilevel procedures, more than one skin incision may be required.

The posterolateral incision is used to gain access to the retroperitoneal space. It guides the safe passage of the dilators and retractor system through the retroperitoneal space. The incision is located approximately four fingerbreadths posterior to the direct lateral incision. It is located just anterior to the intersection of the erector spinae and the abdominal oblique muscles. The skin and subcutaneous tissue are incised. Blunt dissection of the abdominal obliques is carried out, spreading in line with the corresponding muscle fibers. After the final layer of fascia is incised, the retroperitoneal space has been entered.

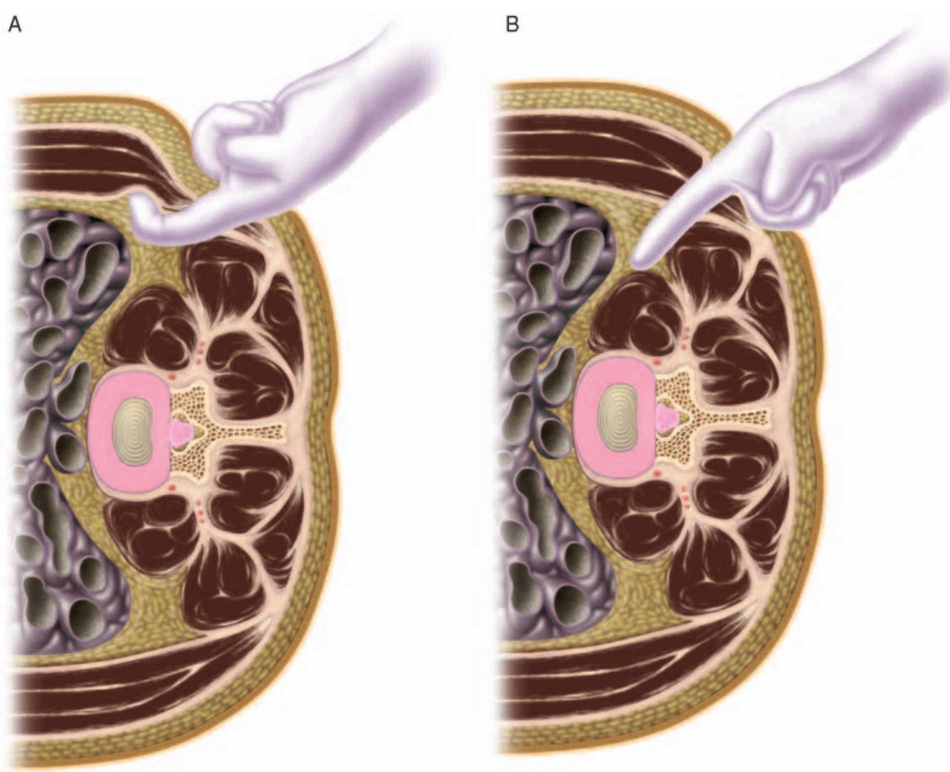

FIGURE 3. (A) With a gentle sweeping motion, the surgeon's finger is used to release the adhesions between the peritoneum anteriorly, and the psoas and abdominal wall. (B) The psoas is palpable lateral to the vertebral body and disc space. (Reproduced with permission from NuVasive, San Diego, CA).

FIGURE 4. The surgeon's finger is turned upwards to the direct lateral incision and the skin is incised. (Reproduced with permission from NuVasive, San Diego, CA).

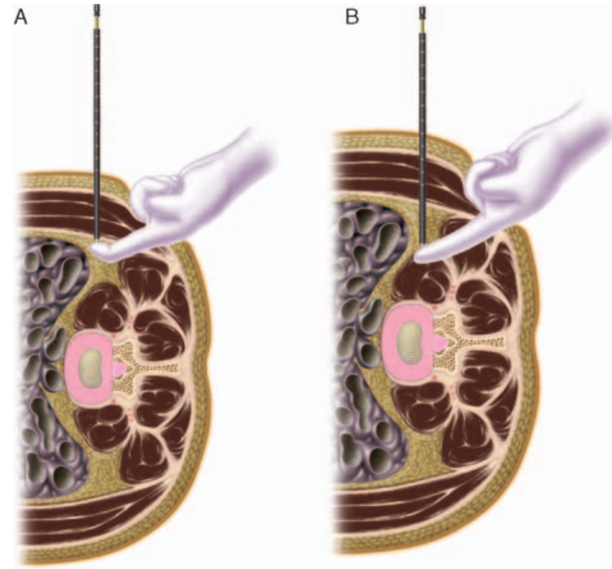

FIGURE 5. (A) The initial dilator is placed through the direct lateral incision. (B) The surgeon's finger safely guides the initial dilator onto the lateral aspect of the psoas. (Reproduced with permission from NuVasive, San Diego, CA).

Using a gentle sweeping motion, the surgeon's finger is used to release the peritoneum from the psoas and abdominal wall, allowing the abdominal contents to fall forward and away from the operative field. The psoas is palpable just lateral to the vertebral body and disc space (Figure 3 A and B). Posteriorly, the tip of the surgeon's finger will come into contact with the transverse processes of the lumbar spine. The surgeon's finger is then turned upwards to the direct lateral skin incision, and the skin is incised (Figure 4). The fascia is incised over the target disc space. The initial dilator is introduced through this incision, and the surgeon's finger is used to guide it safely through the retroperitoneal space and onto the lateral surface of the psoas (Figure 5 A and B). Biplanar fluoroscopy ensures that the initial dilator is centered over the disc space of interest (Figure 6 A and B).

The one-incision technique, if employed, utilizes the direct lateral incision only. It may be favored for cosmetic reasons, however, it is important to note that adhesions between the peritoneum and the abdominal wall may place the peritoneum and its contents at risk. Surgeons utilizing the one-incision technique must use extreme caution during the initial approach to the retroperitoneal space.

Transpsoas Access and Disc Exposure

The nerves of the lumbar plexus are located within the substance of the psoas muscle. Anatomic studies have shown that they are most often found in the posterior third of the

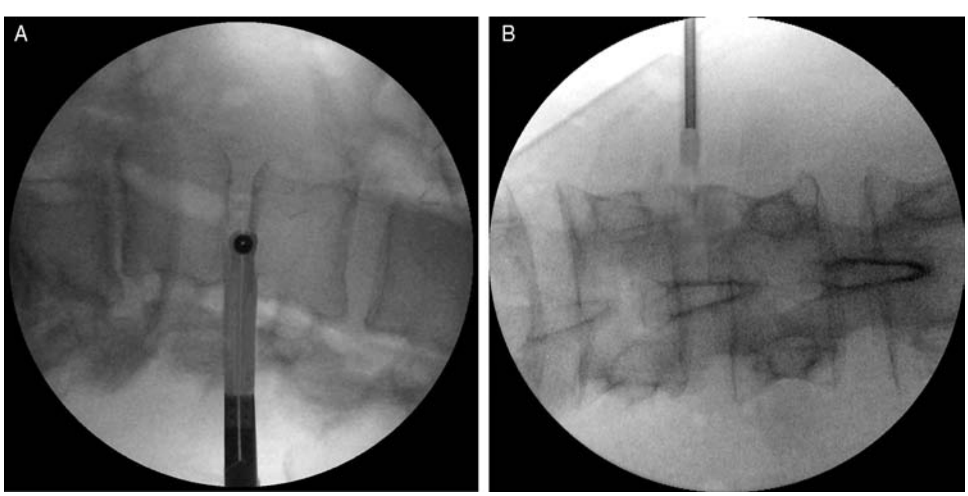

FIGURE 6. Lateral (A) and anteroposterior (B) fluoroscopic images ensure that the initial dilator is centered over the target disc space. (Reproduced with permission from NuVasive, San Diego, CA).

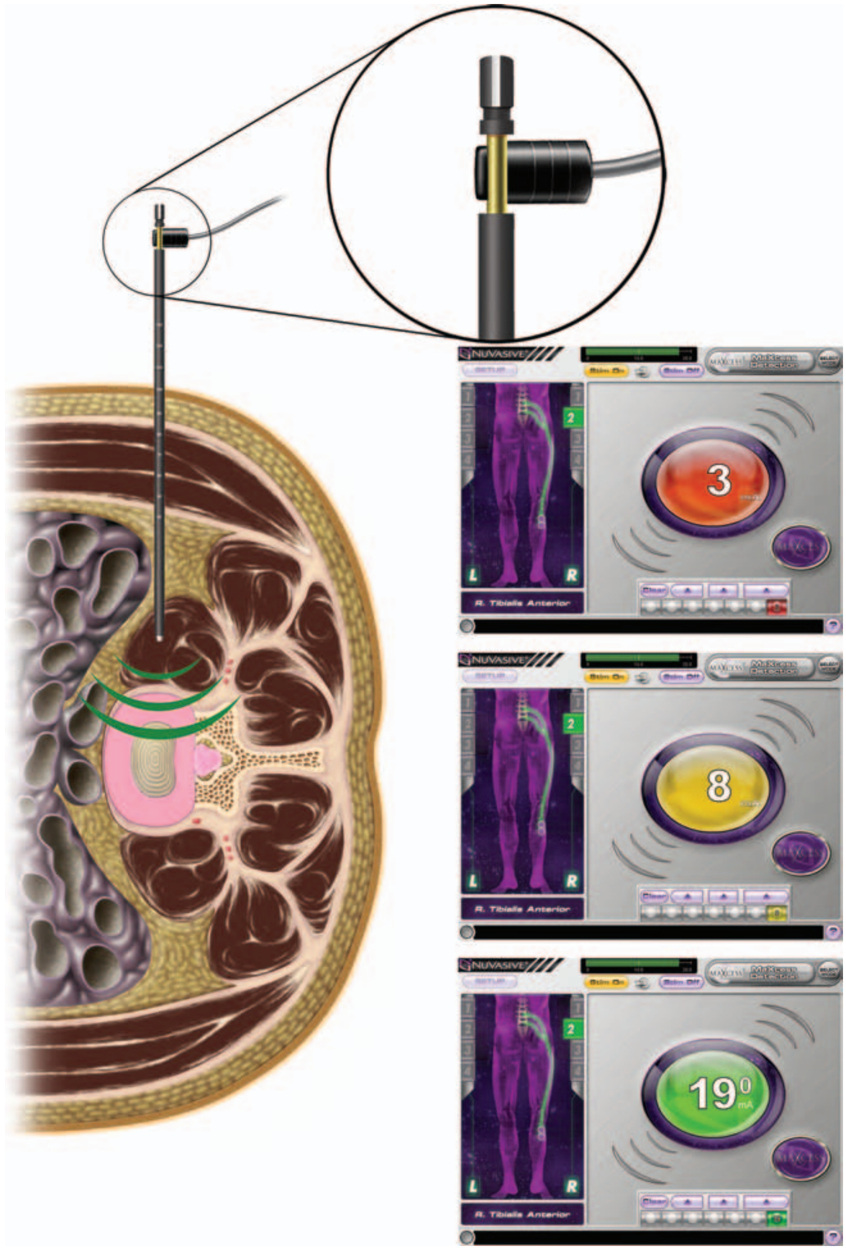

FIGURE 7. Real time Neurovision EMG monitoring is performed as the dilators are passed through the psoas. The surgeon is alerted to the proximity of the nerves of the lumbar plexus by a series of audible and visual signals. (Reproduced with permission from NuVasive, San Diego, CA).

muscle.[44,45] In addition, the genitofemoral nerve lies on the anterior surface of the psoas. Safe passage through the psoas is entirely dependent upon EMG monitoring. The XLIF dilators have stimulating electrodes at their tips. A stimulating clip is attached to the other end, allowing real time Neurovision EMG monitoring (Nuvasive, San Diego, CA) as the psoas is traversed (Figure 7). To minimize the risk to the lumbar plexus, the dilators should enter the psoas at the junction of the anterior and middle thirds. A radiolucent blade or tubular retractor system is placed over the largest dilator and docked on the lateral aspect of the disc space. Care should be taken to ensure that the abdominal contents are protected anteriorly during this maneuver. The retractor system is then secured to the operating table and expanded. The retractor should not be expanded past the midportion of the vertebral body to minimize the possibility of segmental vessel injury (Figure 8).

Discectomy and End Plate Preparation

Disc space preparation is carried out in the usual fashion with a few important caveats. A lateral annulotomy is performed followed by a complete discectomy using pituitary rongeurs and curettes (Figure 9). Over-aggressive decortication of the

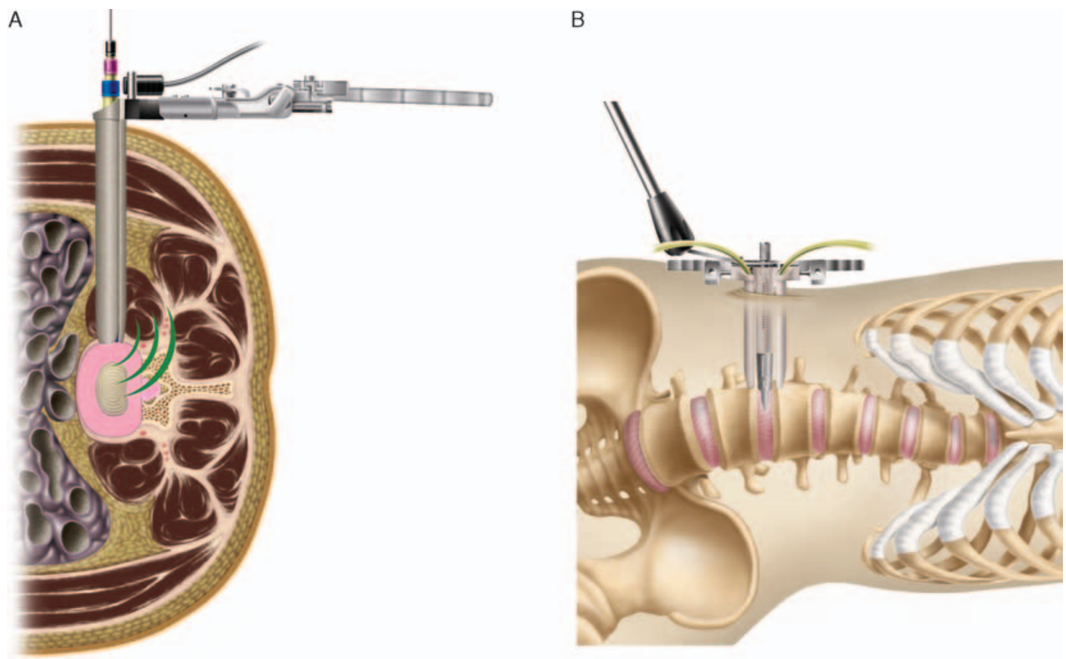

FIGURE 8. (A) The retractor is placed over the largest dilator and docked on the lateral aspect of the disc space. (B) The retractor is secured to the operating table and expanded. (Reproduced with permission from NuVasive, San Diego, CA).

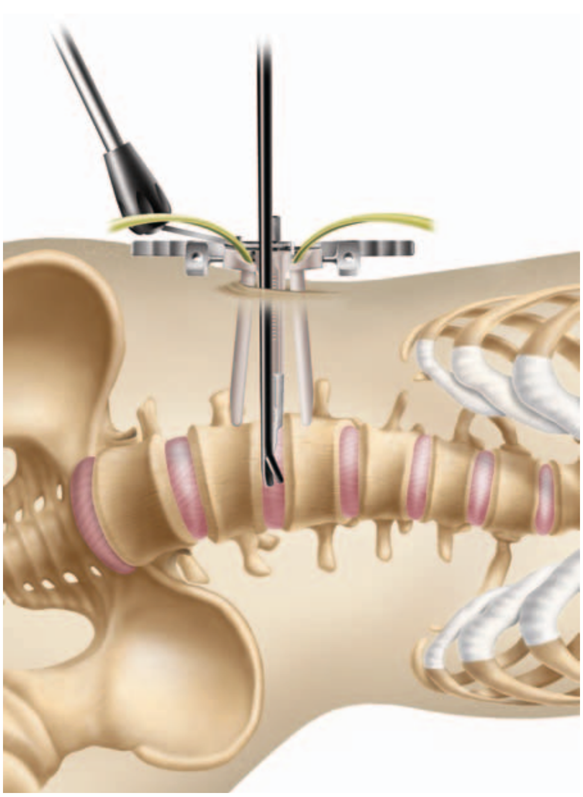

FIGURE 9. Complete discectomy and endplate preparation is carried out using a series of pituitary rongeurs and curettes. (Reproduced with permission from NuVasive, San Diego, CA).

endplates should be avoided to minimize the risk of graft subsidence. The contralateral annulus is released by passing a Cobb elevator completely across the disc space. Both the anterior annulus and the posterior annulus are preserved. It is essential to ensure that the patient has not shifted position during the course of the procedure and that instruments are placed directly across the disc space. This is best confirmed on a cross-table true AP fluoroscopic image. Any deviation can result in oblique passage of instruments across the disc space and potentially catastrophic neurologic or vascular injury.

Interbody Implant Placement

The appropriate size interbody implant is determined after trial positioning. The implant is filled with graft material (Figure 10). Under biplanar fluoroscopic guidance, the implant is carefully impacted completely across the anterior to middle one-third of the disc space (Figure 11). Placing the implant over the outer rim of the end plate on each side provides maximum support because of the strength of the ring apophysis (Figure 12). Supplemental lateral plate fixation may be used in favor of posterior fixation depending on individual patient factors and surgeon judgment. Hemostasis is achieved, and the wounds are irrigated and closed in layers. A drain is not typically necessary (Figure 13).

POSTOPERATIVE CARE

After surgery patients typically exhibit all of the benefits of minimally invasive surgery. They are mobilized on the first

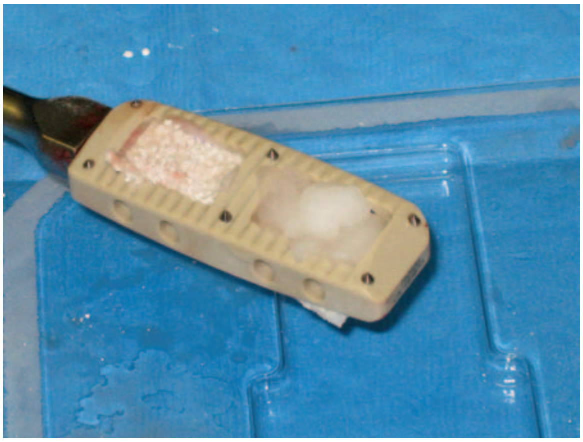

FIGURE 10. Interbody cage filled with the surgeon's choice of bone graft or any of a variety of commercially available bone graft substitutes.

postoperative day. A TLSO brace may be used at the surgeon's discretion. Most patients are discharged home 1 to 3 days after an isolated XLIF procedure.

DISADVANTAGES AND POTENTIAL COMPLICATIONS OF XLIF

XLIF seeks to avoid the anterior and posterior approach-related complications outlined above. However, as with any other operative technique, it is not without its own unique set of disadvantages and potential complications. The XLIF procedure cannot be used to treat pathology involving the L5-S1 intervertebral disc; exposure is limited by the ipsilateral iliac crest. Furthermore, XLIF relies on indirect decompression of the neural elements through restoration of foraminal dimensions. Patients with severe stenosis from facet or ligamentum hypertrophy may require an additional posterior approach to achieve complete decompression.

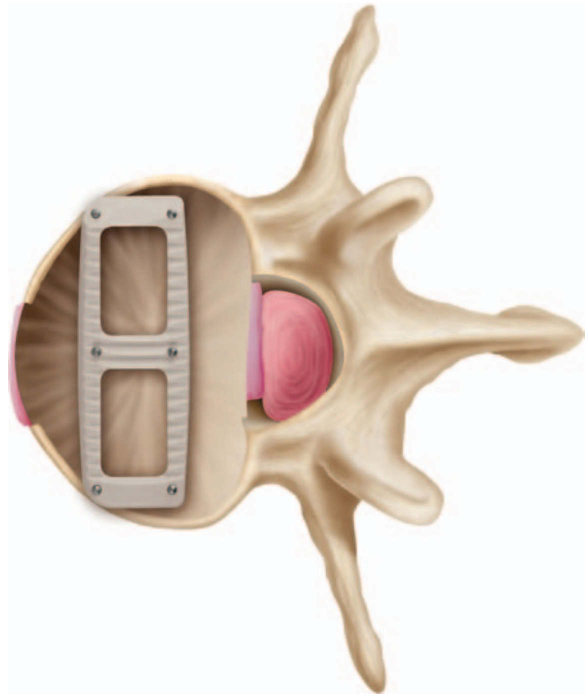

FIGURE 12. The implant should rest on the outer rim of the endplate to minimize the risk of subsidence. (Reproduced with permission from NuVasive, San Diego, CA).

Potential complications of the lateral approach are mostly related to the psoas and the nerves of the lumbar plexus that lie within it. The nerves of the lumbar plexus and the genitofemoral nerve are at risk as the psoas is traversed. The real-time EMG monitoring during this critical stage of the procedure can reliably detect the proximity of neural structures and signal the surgeon to redirect.[46] Still, post-operative groin or thigh dysesthesias may occur in some

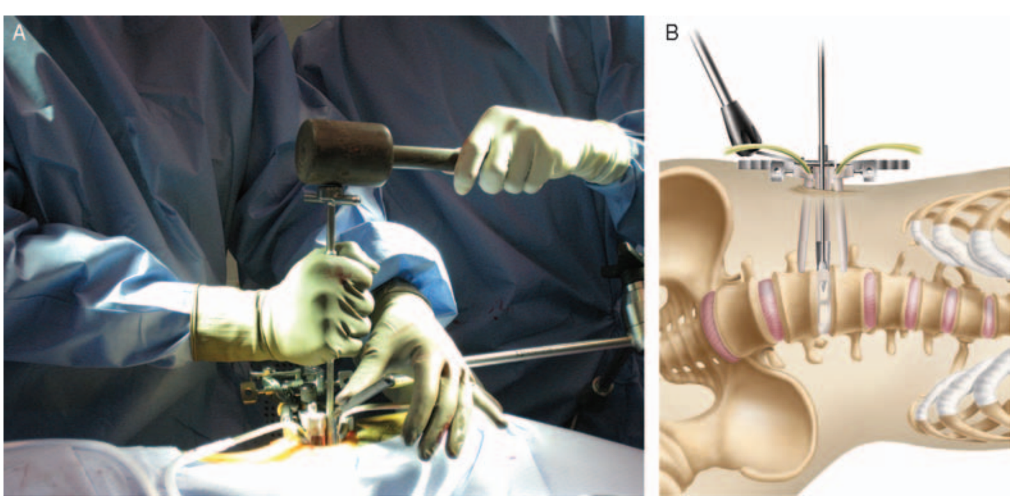

FIGURE 11. Intraoperative photograph (A) and schematic representation (B) of the implant carefully impacted across the anterior to middle one-third of the disc space. (B reproduced with permission from NuVasive, San Diego, CA).

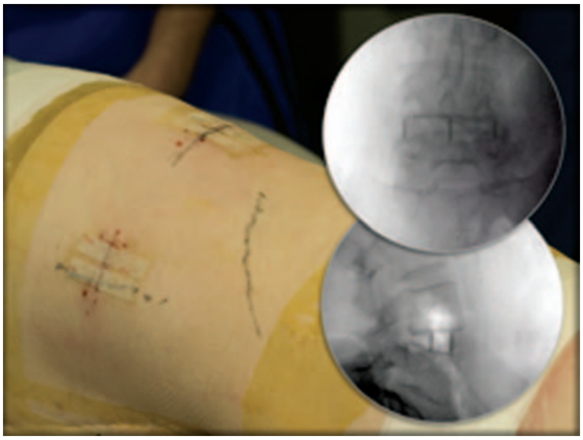

FIGURE 13. Appearance of the incisions following closure. Final anteroposterior and lateral fluoroscopic images of the implant (inset).

patients. In one recent series of patients with degenerative lumbar scoliosis, three of 12 patients experienced transient groin or thigh dysesthesias.[47•] These all resolved within 6 weeks. In our experience, occasionally these may even last up to 6 months. Direct trauma to the psoas also frequently leads to transient hip flexor pain and weakness during the early postoperative period. Patients should be informed of these possibilities during the preoperative discussion.

Major neurologic, vascular, or implant related complications of the XLIF procedure have not been published. Still, meticulous attention to detail and to the techniques outlined in this review, are essential to minimize the risk of complications.

CLINICAL EXPERIENCE WITH XLIF

The safety and efficacy of XLIF has been demonstrated by a number of researchers who have presented their experience with XLIF at various national and international meetings.[46,48–52] In the largest of these series, Wright[46] reported the results of XLIF in 145 patients treated by 20 surgeons in the United States. All patients underwent XLIF for the treatment of lumbar degenerative disc disease. The number of levels treated varied from one to four (72% single level, 22% two levels, 5% three levels, and 1% four levels). Interbody spacers (poly-ether-ether-ketone (PEEK) 86%, allograft 8%, or cage 6%) were used in conjunction with bone morphogenic protein (52%), demineralized bone matrix (39%), or autograft (9%). Twenty percent of the cases were stand-alone interbody, 23% used a lateral rod-screw construct, and 58% used posterior pedicle screws. Average operative time was 74 minutes (range, 30–150 minutes). Average blood loss was 88 ml (range, 25–450 ml). The author noted a 46% incidence of EMG-directed instrument repositioning during the trans-psoas approach. Most patients ambulated on the day of surgery and were discharged on the first postoperative day. No major complications were reported.

There are still only a few published studies on outcomes after XLIF. Those that are available are mostly small case series. Despite their small numbers, these studies have demonstrated the safe and effective application of the XLIF procedure in patients with degenerative disc disease and adult deformity.[4,47•,53•]

At our institution, XLIF has been performed successfully and reliably in patients with degenerative conditions, spondylolisthesis and adult deformity (primary and revision cases). We recently reported the early results of the XLIF approach in 13 patients (mean age 60.5 years, range, 37–84 years) who had multilevel (two or more levels) XLIF for the treatment of adult lumbar scoliosis greater than 30 degrees.[53] A mean of three levels (range, two to five) were treated and all were combined with posterior spinal fusion and instrumentation. Average follow-up was 9 months (range, 2–28 months). Radiographically, significant improvements in lumbar curve magnitude and lumbar lordosis were achieved. Two XLIF-related complications occurred: one graft required revision due to migration, and one hernia occurred at the site of the XLIF incision, which did not require operative treatment. All cases of psoas muscles weakness or thigh numbness or pain resolved in patients who had a minimum of 6 months follow-up. Short-term postoperative visual analog scale (VAS), Scoliosis Research Society (SRS)-22 and Oswestry Disability Index (ODI) scores were improved significantly in comparison to preoperative scores.

To date, there exists no large, multicenter, Level I or Level II studies that examine clinical outcomes of patients after the XLIF approach. Similarly, no published data exist comparing XLIF to other traditional or minimally invasive approaches to lumbar interbody fusion (Figures 14–17; case examples).

CONCLUSION

The goal of any interbody fusion technique is to achieve a solid fusion, restore disc space height and foraminal dimensions, and correct any segmental (sagittal or coronal) imbalance. All of these goals must be achieved while minimizing the potential for complications and morbidity. The XLIF procedure appears to accomplish these goals through a minimally disruptive lateral retroperitoneal trans-psoas approach to the spine. The anterior and posterior approach-related complications are avoided. Neurophysiologic monitoring is an essential component of the procedure to ensure avoidance of the lumbar plexus complications. Minor complications such as lumbar plexus neuropraxia and hip flexor weakness may occur but are transient.

The XLIF procedure is biomechanically advantageous in that it preserves the anterior and posterior osseoligamentous structures of the spine and allows for insertion of a large interbody implant. Restoration of foraminal dimensions and coronal and sagittal balance can be achieved while minimizing the risk of subsidence and implant failure. Further biomechanical research is necessary to better elucidate the role of supplemental posterior or lateral instrumentation.

Early reports have shown that XLIF appears to accomplish all of the goals of interbody fusion, safely and effectively. Large, evidenced based, multi-center studies are needed to provide intermediate and long-term term outcome data with this new technique. As with all new technologies,

FIGURE 14. A 63-year-old woman with low back pain and neurogenic claudication, who previously underwent an L4-5 instrumented fusion for degenerative spondylolisthesis. Anteroposterior (A) and lateral (B) radiographs and sagittal T2 weighted MRI (C) 3 years postoperatively demonstrate severe adjacent segment degeneration at L2-3 and L3-4, with anterolisthesis of L3 on L4. The patient underwent a single stage L2-3 and L3-4 XLIF, followed by posterior decompression, and extension of the fusion to L2. Post-operative anteroposterior (D) and lateral (E) radiographs demonstrate reduction of the listhesis and restoration of disc space height, foraminal dimensions, and lumbar lordosis.

FIGURE 15. A 36-year-old man with chronic, axial low back pain secondary to L4-5 degenerative disc disease, unresponsive to nonoperative treatment. The patient had a positive discogram with concordant pain at L4-5 and a negative control at L5-S1. Pre-operative, anteroposterior (A) and lateral (B) radiographs, and sagittal T2-weighted MRI (C). The patient underwent an L4-5 XLIF with supplementary lateral plate fixation. Post-operative anteroposterior (D) and lateral (E) radiographs.

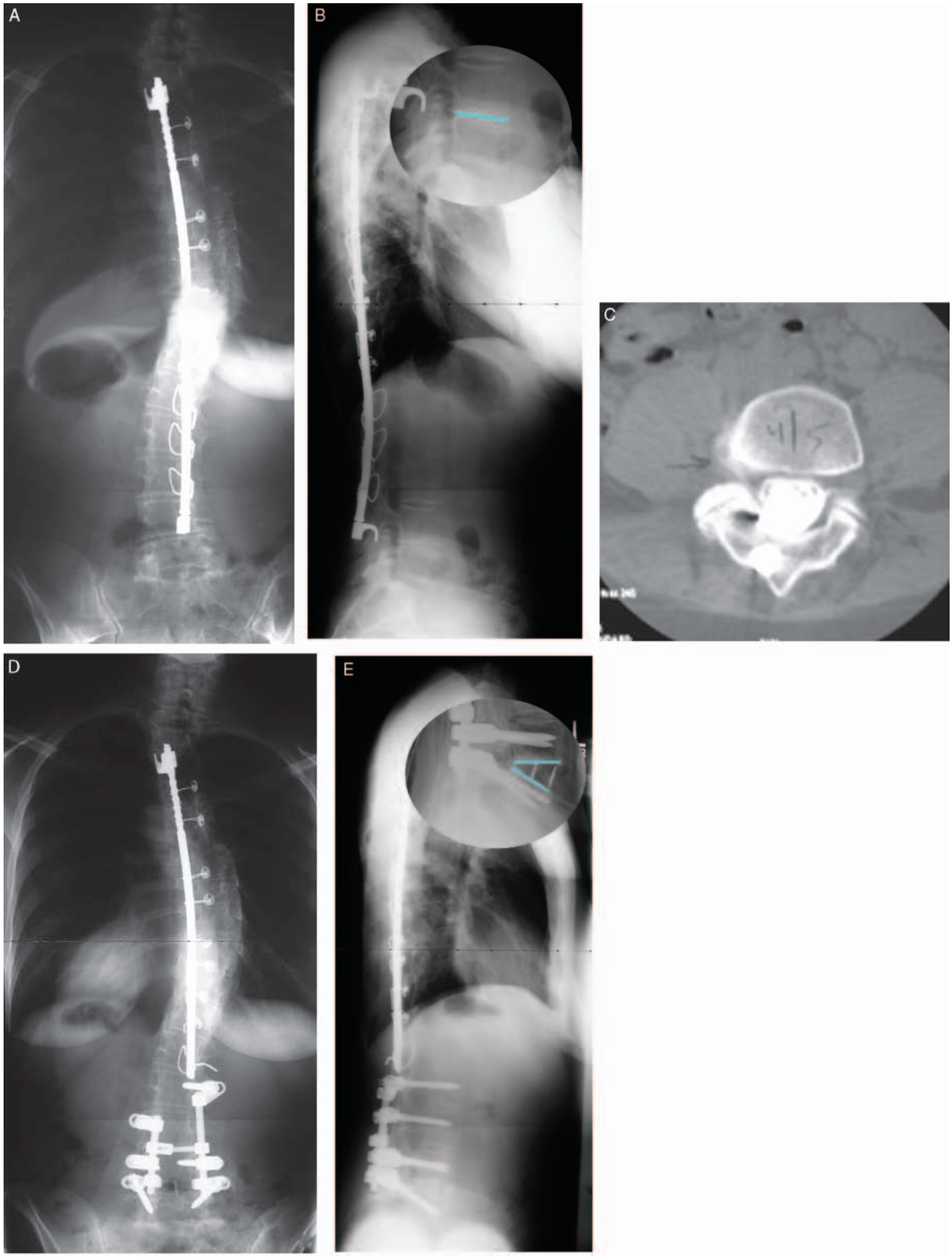

FIGURE 16. A 35-year-old woman with idiopathic scoliosis who had undergone posterior spinal fusion and Harrington instrumentation from T3-L4 in 1984. She had a history of chronic low back pain and right anterior thigh pain for 6 months. Anteroposterior (A) and lateral (B) radiographs demonstrate lumbar flatback deformity, sagittal imbalance, and adjacent segment degeneration at L4-5. Axial CT myelogram at L4-5 (C) demonstrates right foraminal stenosis. She had a positive discogram with concordant pain at L4-5, with a negative control at L5-S1. She underwent L4-5 XLIF, followed by partial removal of the Harrington rod, L3-5 laminectomies and foraminotomies, and posterior fusion and pedicle screw instrumentation, L2-5. Postoperative anteroposterior (D) and lateral (E) radiographs demonstrate restoration of segmental lordosis (inset).

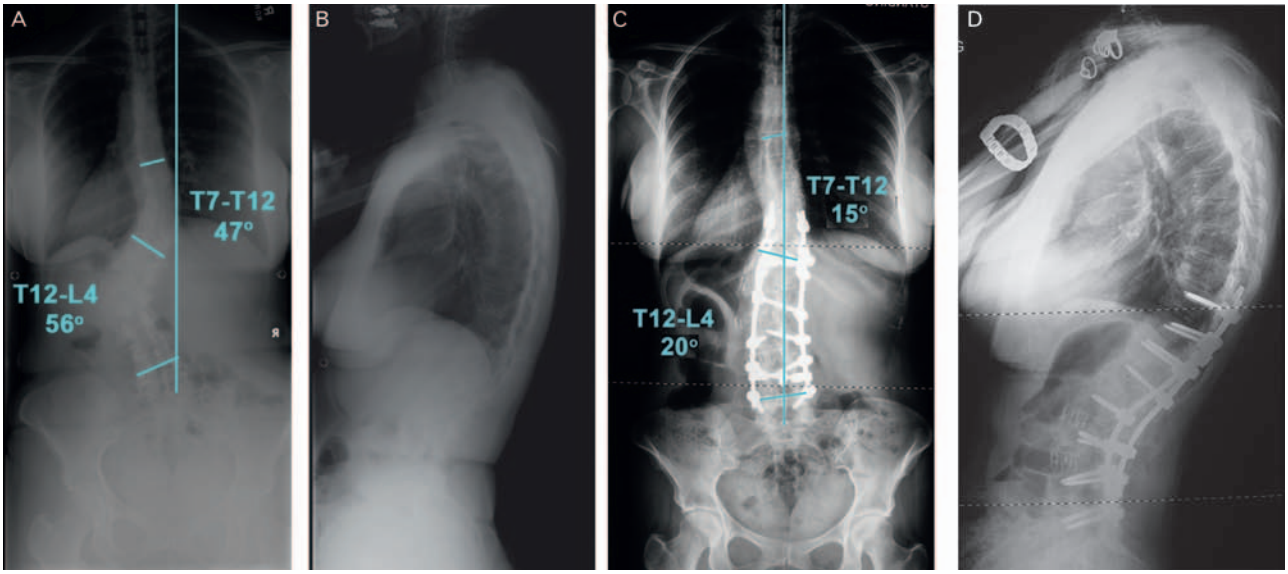

FIGURE 17. A 61-year-old woman with idiopathic scoliosis. Preoperative anteroposterior (A) and lateral (B) radiographs. (C and D) The patient underwent multilevel XLIF at T12-L1, L1-2, L2-3, L3-4, and L4-5, followed by posterior spinal fusion and instrumentation from T10-L5 with improvements in curve magnitude and balance.

eventually this outcome data will need to be compared against traditional and other minimally invasive approaches to lumbar interbody fusion. Finally, it is extremely important for those who want to use this technique to be trained appropriately and to identify a mentor with whom they can observe surgery and communicate regarding proper indications and possible management questions.

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