Minimally Invasive Lumbar Spinal Fusion

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Abstract

Minimally invasive techniques for lumbar spine fusion have been developed in an attempt to decrease the complications related to traditional open exposures (eg, infection, wound healing problems). Anterior minimally invasive procedures include laparoscopic and mini-open anterior lumbar interbody fusion as well as the lateral transpsoas and percutaneous presacral approaches. Posterior techniques typically use a tubular retractor system that avoids the muscle stripping associated with open procedures. These techniques can be applied to both posterior and transforaminal lumbar interbody fusion procedures. Many initial reports have shown similar clinical results in terms of spinal fusion rates for both traditional open and minimally invasive posterior approaches. However, the anterior minimally invasive procedures are often associated with significantly greater incidence of complications and technical difficulty than their associated open approaches. There is a steep learning curve associated with minimally invasive techniques, and surgeons should not expect to master them in the first several cases.

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Lumbar fusion has been successfully used to manage degenerative, neoplastic, developmental, and traumatic conditions of the lumbar spine. Despite its relative safety and success rate, fusion is not without limitations and complications. Advancements in surgical techniques and instrumentation have led to decreased surgical times, improved fusion rates, and decreased complication rates. However, there is often injury to the soft tissues associated with spine fusion as open exposure and prolonged retraction can lead to tissue necrosis. There is also risk of injury to neurovascular structures during the surgical exposures.

The effect of prolonged muscle retraction in terms of muscle damage and postoperative clinical results has been investigated in clinical and basic research science studies. Datta et al[1] measured intramuscular pressure of the paraspinous muscles during two-level lumbar decompression in 20 patients. Placement of deep self-retaining retractors was associated with a rapid increase in muscle pressure. Additionally, continuous retraction of longer than 60 minutes was associated with significantly worse pain and disability outcomes at 6 months postoperatively ($P < 0.05$). The authors suggested that periodic relaxation of the retractors might reduce postoperative back pain.[1] These clinical results have been verified by histologic findings of muscle fiber necrosis and degeneration of neuromuscular junctions following prolonged muscle retraction.[2,3] Kawaguchi et al[4] determined that the effects of prolonged retraction can be prevented by periodic release of the retractors. A 5-minute release of the retractors after each hour was effective in preventing muscle injury in a rat model.

Less invasive surgical exposures have been developed in an attempt to decrease the complications related to traditional open exposures, including infection and wound healing problems. These techniques have been successfully applied to other types of surgery. One of the best examples overall is laparoscopic cholecystectomy; an example from the field of orthopaedic surgery is arthroscopic partial meniscectomy. The use of these techniques, which have virtually eliminated the need for open surgical procedures, has led to decreased surgical time, complications, and associated morbidities. There are few data on the results of minimally invasive surgery for lumbar fusion compared with other minimal exposure surgeries.

Anterior Approaches

Several anterior approaches have been proposed for spinal fusion. In 1932, Carpenter[5] initially described the anterior lumbar interbody fusion (ALIF) technique for treatment of spondylolisthesis. Since then, there have been many modifications of the technique, including open transperitoneal,[6] laparoscopic transperitoneal,[7] open retroperitoneal,[8] mini-open retroperitoneal,[9] and endoscopic retroperitoneal.[10] Recently, other approaches have been described, including the lateral transpsoas and the anterior presacral. Although any of these can be performed as a stand-alone procedure, each is more commonly combined with posterior spinal instrumentation.

Laparoscopic-assisted Approaches

In the 1990s, the use of laparoscopic-assisted techniques in general and gynecologic surgery prompted the development of laparoscopic-assisted ALIF. In this technique, the patient is placed supine on a radiolucent surgical table. Bolsters are placed under the hips to accentuate lumbar lordosis. The table is placed in a steep Trendelenburg position to assist in moving the abdominal contents superiorly out of the surgical field. Four portals are typically used: two low paramedian incisions, for working portals; one portal for instrumentation, placed in the midline suprapubic region; and a camera portal, created via an umbilical incision. The disk space is approached, and the middle sacral artery and vein are ligated and retracted out of the way. The iliac veins are then mobilized and retracted. A marker is placed in the midline of the disk, and its location is confirmed by fluoroscopy. Diskectomy is then performed, and a titanium threaded cage or allograft bone dowels are inserted into the disk space.

Zucherman et al[7] reported one of the first series of laparoscopic transperitoneal approaches to ALIF. Seventeen patients were studied, with an average 8-month follow-up (range, 6 to 12 months). Two patients required conversion to an open procedure. It was felt that despite the long learning curve, this technique could develop into a safe and effective one, with reduced complications. More recently, Chung et al[9] compared the results of laparoscopic and mini-open ALIF at 2-year follow-up. Twenty-five patients were treated via the laparoscopic approach and 22 via the mini-open ALIF approach. Three patients had to be converted from the laparoscopic to the mini-open procedure. No significant differences were noted in length of hospital stay, blood loss, fusion rate, pain scale, disability index, or patient satisfaction. Surgical time was significantly longer ($P = 0.001$) with the laparoscopic technique. The authors concluded that although similar clinical and radiographic results were obtained with both approaches, no significant benefits were obtained from using the laparoscopic approach that would justify the long learning curve and technical difficulty associated with it.

Others have found significantly higher rates of complications associated with laparoscopic ALIF. Zdeblick and David[10] reported a 20% complication rate with the laparoscopic approach to L4-5, compared with a 4% complication rate with the open technique. Additionally, they found that there was inadequate exposure in 16% of the laparoscopic cases. Kaiser et al[11] reported a significantly higher rate of retrograde ejaculation with the laparoscopic technique compared with mini-open ALIF (45% versus 6% [$P < 0.05$]).

Retroperitoneal Approach

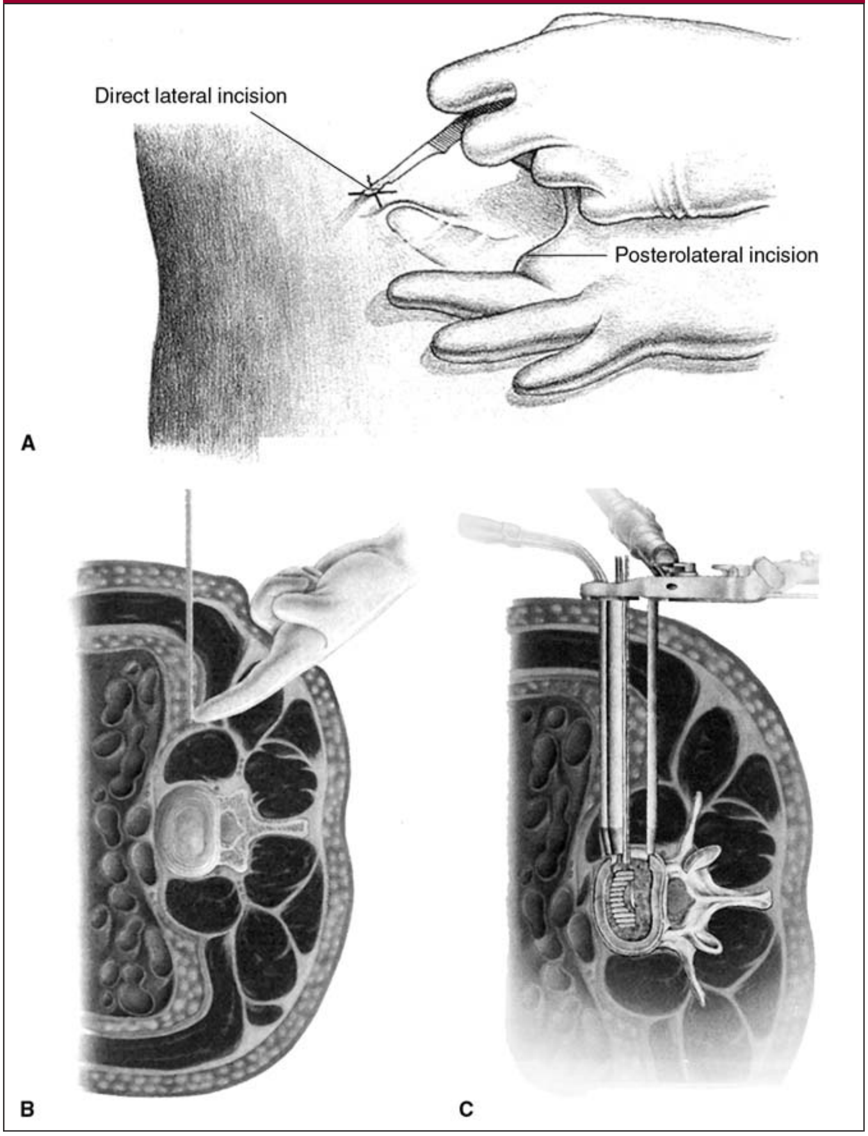
Harmon[12] first described the retroperitoneal approach in 1963. This approach was later modified by Mayer,[13] who described a minimally invasive muscle-splitting approach. The skin incision can be made progressively smaller as the surgeon becomes more comfortable with the approach, which is relatively well-known and used by spine surgeons. In a series of 56 patients, Saraph et al[14] compared the traditional retroperitoneal approach with the minimally invasive approach described by Mayer. At a mean 5.5-year follow-up, no significant differences were noted in fusion rate or complications. The minimally invasive approach had markedly less blood loss, shorter surgical times, and improved clinical outcomes.

Extreme Lateral Interbody Fusion

The endoscopic lateral transpsoas or extreme lateral interbody fusion (XLIF) (NuVasive, San Diego, CA) approach was recently described by Bergey et al.[15] This exposure is performed with the patient in the right lateral decubitus position. A small incision is made at the level of the surgical disk space at the lateral border of the paraspinous muscles (Figure 1, A). Finger dissection is performed to open the retroperitoneal space down to the psoas muscle. Another small incision is made over the psoas muscle, and sequential dilators are inserted down to the psoas muscle (Figure 1, B). Electromyographic monitoring is performed while passing through the psoas muscle. The dilators are advanced to the level of the disk. The disk space is then evacuated, and the implants are inserted (Figure 1, C). The 21 patients treated by Bergey et al[15] had a mean surgical time of 149 minutes, blood loss of 150 mL, and a hospital stay of 4.1 days. At a mean 3.1-year follow-up, these patients had an average decrease of 5.9 on the visual analog pain scale.

One significant potential risk of XLIF is injury of the genitofemoral nerve, which arises from the L1 and L2 nerve roots and passes through the inner border of the psoas at the L3-4 level. Staying in the anterior one third of the psoas and directly visualizing the genitofemoral nerve is recommended. Neural monitoring was performed using the Neurovision (NuVasive) electromyography-based monitoring system.[15] Despite these precautions, six patients (30%) reported groin or thigh paresthesias postoperatively; this is consistent with injury to the genitofemoral nerve. Paresthesia resolved within 4 weeks in four of these six patients. There were no reports of muscle weakness in the femoral nerve distribution or of vascular injury. The authors concluded that this technique is effective for anterior exposure to L1-L4. The major advantage of the XLIF technique is that there is no need to mobilize the great vessels or sympathetic plexus. Although a relatively high rate of groin numbness was reported in this series, other series have reported no complications related to the XLIF technique.[16,17] Patients should be warned of the possible risk of groin numbness associated with the XLIF technique.

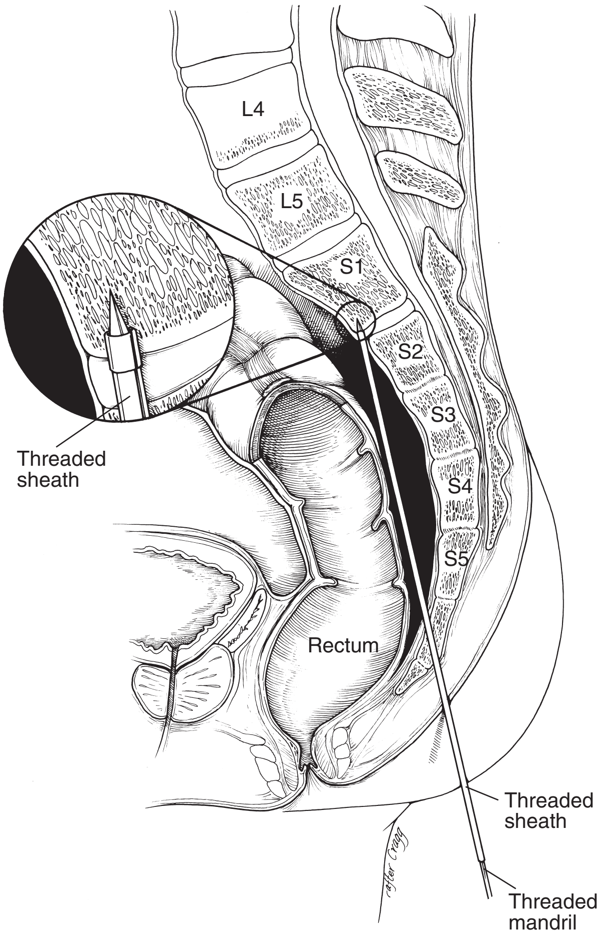
Figure 1



Surgical technique for the endoscopic lateral transpsoas approach. **A,** A small incision is made over the psoas muscle. **B,** A series of dilators is inserted through the retroperitoneal space and through the psoas muscle under electromyographic monitoring. **C,** The disk space is cleared, and the interbody implant is inserted. (Reproduced with permission from NuVasive, San Diego, CA.)

Although the lateral transpsoas approach is currently recommended for exposure to the L1-L4 levels, this approach can be used for either the L4-L5 or L5-S1 levels.[18] There are two main limitations to using the transpsoas approach to reach these lower levels. The first problem is the location of the great vessels. The L5-S1 level, located below the bifurcation of the great vessels, is more easily reached with the more traditional anterior transperitoneal approach. With the lateral transpsoas approach, significant dissection and mobilization of the vessels is required to expose distal to L4. The second limitation is the location of the iliac crest. To reach distal to the L3-4 interspace, it may be necessary

Figure 2



The passage of a blunt trocar using the AxiaLIF percutaneous, presacral approach.

to remove a portion of the iliac crest to enable placement of a portal.[18]

Axial Lumbar Interbody Fusion

Axial lumbar interbody fusion (AxiaLIF [TranS1, Wilmington, NC]), done via a percutaneous, presacral approach to the anterior lumbar spine, was initially described by Cragg et al.[19] The AxiaLIF technique involves percutaneous placement of a trocar through a 4-mm incision over the paracoccygeal notch. The trocar is advanced along the anterior aspect of the sacrum under fluoroscopic guidance until proper trajectory into the S1 body is achieved (Figure 2). Cragg et al[19] describe the results of cadaveric studies, animal studies, and human pilot studies. The technique was performed in 15 cadaveric specimens and 6 pigs. There were no instances of vascular or bowel injury. In the human pilot study, the AxiaLIF technique was used to obtain biopsy specimens from three patients. There were no reported complications in any case.[19] Marotta et al[20] further illustrated this technique and presented a case series. Although early reports have been encouraging, more substantial testing is needed before the AxiaLIF technique is put into widespread use.

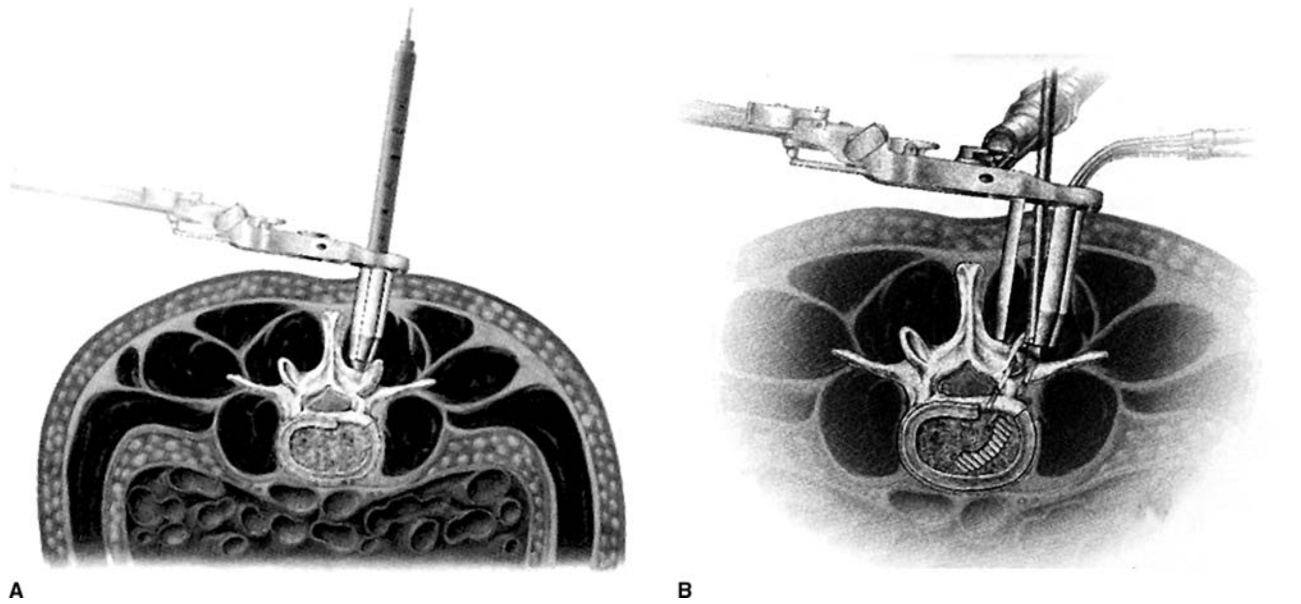
Posterior Approaches

A greater effort has been applied to the development of minimally invasive approaches to the posterior lumbar spine. However, much of this work has focused on diskectomy and decompression, with fewer applications related to posterior lumbar fusion. The initial modifications of posterior lumbar surgery were developed with the advent of the operating microscope. This tool allowed for a smaller incision and reduced amount of surgical dissection. The next advancement was the development of percutaneous diskectomy techniques, including chemonucleolysis, automated percutaneous diskectomy, laser-assisted percutaneous diskectomy, and intradiskal electrothermal therapy. A review of these techniques has been performed.[21]

Many of the minimally invasive approaches to the posterior lumbar spine use a tubular retractor system inserted through muscle fascicles, which eliminates the need for traditional muscle-stripping techniques and minimizes the incision and tissue disruption.[22] Examples of retractor systems include the METRx dilator system (Medtronic Sofamor Danek, Memphis, TN) and the MAXCESS system (NuVasive). Maintaining the normal soft-tissue envelope of the paraspinous muscles allows for more normal physiologic motion of the spine.[23]

A 2- to 3-cm longitudinal skin incision is made approximately 3 cm lateral to the midline, and, under fluoroscopic guidance, sequentially larger tubular retractors are placed to allow a working portal (Figure 3). The initial dilator has an approximate outer diameter of 4 mm. The dilators are exchanged up to a maximum outer diameter of 15 to 20 mm. The skin incision for these techniques is similar to that for microscopic diskectomy. Because of the gradual dilation through muscle fibers, there is no associated soft-

Figure 3



Surgical technique for minimally invasive posterior lumbar interbody fusion. A small longitudinal skin incision is made approximately 3 cm lateral to the midline of the surgical level. **A,** A series of dilators is inserted and passed down to the medial aspect of the facet joint. **B,** After decompression is performed, the disk space is cleared and the interbody implants are placed. (Reproduced with permission from NuVasive, San Diego, CA.)

tissue muscle stripping from the posterior elements of the spine. Posterior minimally invasive techniques can be done using either loupe magnification or an operating microscope. Specially designed instruments have been produced to allow improved visualization. Numerous other tubular retractor systems and minimally invasive pedicle screw systems are available, including Aperture, Pipeline, and Viper (DePuy Spine, Raynham, MA); Pivot System (Globus Medical, Phoenixville, PA); VuePASS (EBI, Parsippany, NJ); and Atavi (Endius, Plainville, MA). There is very limited peer-reviewed literature evaluating any of these new systems.

Foley and Gupta[24] reported on one of the first clinical series using a tubular retractor system for minimally invasive pedicle screw fixation of the lumbar spine. Twelve patients underwent either one- or two-level pedicle screw instrumentation using the Sextant system (Medtronic Sofamor Danek). Each of the posterior pedicle screw fixations was combined with fusion: 10 ALIF, 1 minimally invasive interbody fusion through a retroperitoneal approach, and 1 percutaneous onlay fusion using tubular retractors. The Sextant system allows for percutaneous placement of pedicle screws and rods. At a mean 13.8-month follow-up, the authors reported that the system was safe and effective.

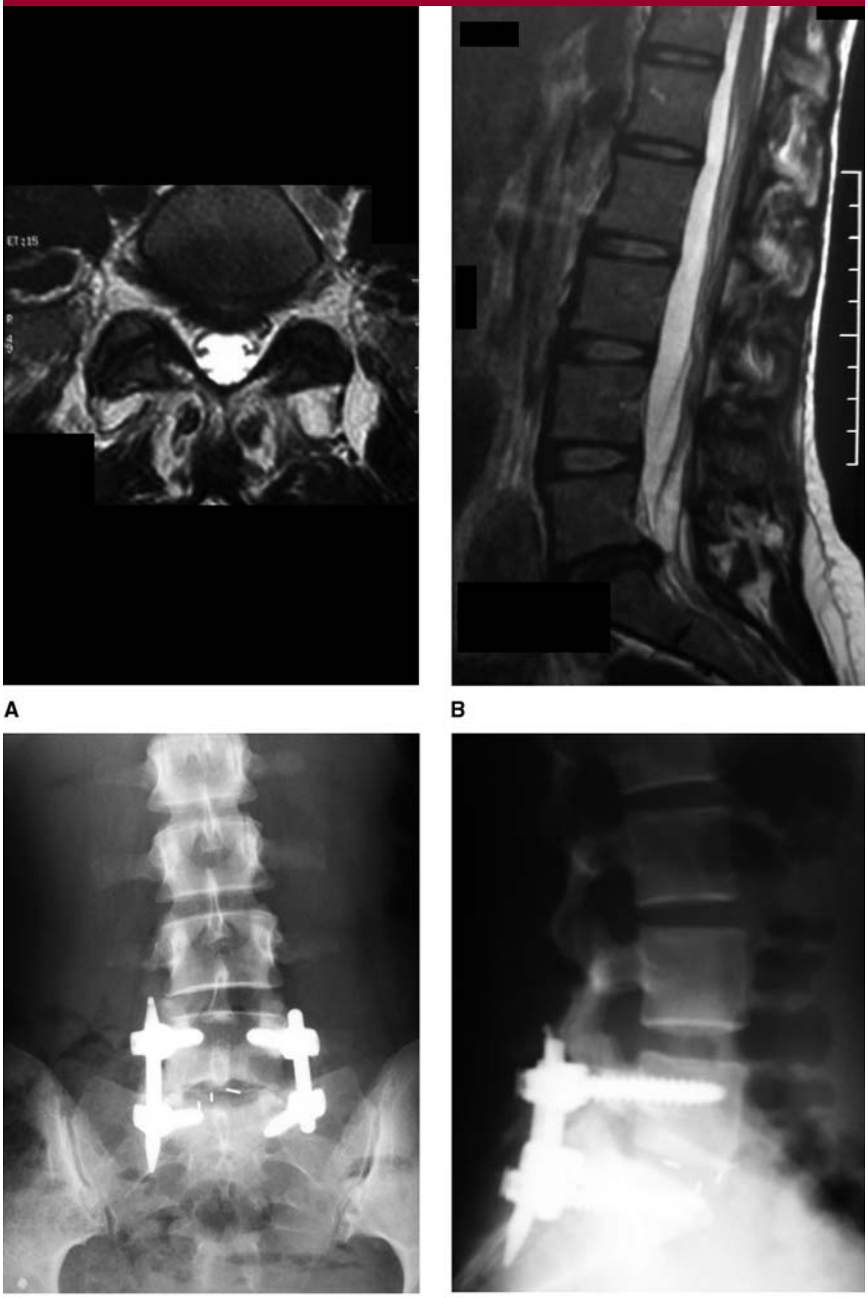
Transforaminal Lumbar Interbody Fusion

Transforaminal lumbar interbody fusion (TLIF) was developed as a variant of the posterior lumbar interbody fusion (PLIF) technique. TLIF uses a posterior approach to the spine through a far lateral portion of the vertebral foramen. The goal with TLIF is to achieve posterior interbody fusion with fewer risks and limitations than are associated with PLIF. Specifically, the far lateral approach enables significantly less retraction of the neural structures. Additionally, TLIF can be performed throughout the lumbar spine, whereas PLIF can be done only at L3-4 and below. Another major advantage of the TLIF technique is that it can be performed unilaterally, thus preserving the interlaminar surface of the contralateral side, which can be used as an additional fusion site. The TLIF approach also allows the muscular envelope to be maintained.

Schwender et al[25] provided data on 49 patients who underwent minimally invasive TLIF. Average surgical time was 240 minutes, blood loss was 140 mL, and hospital stay was 1.9 days. No patient required conversion to an open procedure. At a minimum 18-month follow-up, significant improvement was found in both the average visual analog scale score (7.2 to 2.1) and Oswestry Disability Index score (46 to 14).

TLIF is a technically demanding procedure with a substantial learning curve. However, it has been reported to provide several benefits over the more traditional PLIF technique. Humphreys et al[26] retrospec-

Figure 4



Preoperative axial **(A)** and sagittal **(B)** magnetic resonance images demonstrating large central disk herniation at L5-S1 in a 32-year-old woman. Anteroposterior **(C)** and lateral **(D)** postoperative radiographs after the patient underwent minimally invasive L5-S1 fusion.

tively reported their clinical and radiographic results of PLIF versus TLIF and found that the TLIF procedure offers a similar fusion rate, surgical time, and hospital stay, with significantly less blood loss ($P < 0.01$) than the PLIF technique. Two notable advantages of TLIF are the ability to preserve the posterior paraspinous muscular envelope and the decreased need for retraction of the neural elements compared with PLIF. Combining the TLIF procedure with a minimally invasive approach could provide an improved technique for achieving solid fusion with substantially less soft-tissue damage than with TLIF alone.

Manos et al[27] reported on a cadaveric study comparing the amount of disk material removed and the surface area of end plate exposed when using a minimally invasive TLIF versus an open TLIF technique. Six cadaveric spines with 26 disks were used in the study; no differences were identified between the open versus the minimally invasive TLIF technique. Prospective randomized studies of the TLIF procedure are needed to further compare its results with those of the PLIF procedure.

Another potential application of the minimally invasive approach to the lumbar spine is for the removal of spinal fixation. Although in most patients spinal fixation is left in place, broken or painful hardware may require removal. Unfortunately, an extended exposure is usually required to remove spinal fixation. Salerni[28] retrospectively studied the records of patients who underwent minimally invasive techniques to remove posterior spinal fixation. Six patients underwent removal of spinal instrumentation using a tubular retractor system. Average surgical time was 33 minutes, and average hospital stay was 1 day. No complications were reported.

Case Example

A 32-year-old woman reported low back pain with mild lower extremity radiculopathy that did not improve with 6 months of nonsurgical management. Preoperative imaging studies revealed a large central disk herniation at L5-S1 (Figure 4, A and B). The patient elected to undergo minimally invasive lumbar fusion at L5-S1. Percutaneously placed pedicle screws were inserted on the left side using Sextant instrumentation (Medtronic Sofamor Danek). A minimally invasive TLIF was performed from the right side using Legacy instrumentation (Medtronic Sofamor Danek) through a 2-cm incision with a quadrant retractor system. The patient tolerated the procedure well without complications (Figure 4, C and D). At final follow-up, the patient had nearly complete resolution of her low back and extremity pain.

Advantages and Disadvantages of Minimally Invasive Spinal Fusion

Despite increased public interest in and industry marketing of minimally invasive spinal fusion, there is no clear understanding of the actual advantages and disadvantages associated with it (Table 1). Few clinical series have demonstrated the surgical techniques or reported the results. Based on basic science studies, it seems likely that there would be less soft-tissue necrosis with minimally invasive exposures; however, the clinical significance of this has not yet been proved. No reduction in either wound breakdown or infection has been reported with less invasive techniques.

The primary proposed advantages of the minimally invasive anterior approaches are decreased soft-tissue dissection, improved visualization, and decreased risk of infection, potential advantages that have not yet been confirmed. Although there is less soft-tissue dissection, no proven clinical benefit has been documented. The major disadvantages of these approaches are a long learning curve, increased surgical times, and increased risk of retrograde ejaculation.

Somewhat better results have been achieved with the minimally invasive posterior approaches to the lumbar spine. Advantages of these approaches include less soft-tissue dissection, maintenance of the soft-tissue envelope, and less blood loss. By maintaining the normal posterior muscular envelope surrounding the posterior elements of the lumbar spine, more normal physiologic motion is achieved postoperatively. Additionally, there is less risk of adjacent-level instability because the posterior ligamentous structures are not disrupted.[23] Although this has been shown biomechanically, there is little clinical evidence to corroborate this theory. Disadvantages of these approaches include the technically demanding skills, increased surgical times, and limited surgical exposure.

In most studies, there is a similar clinical outcome whether a traditional open technique or a minimally invasive approach was used. The increased risk and steep learning curve of the minimally invasive anterior approach to lumbar fusion are not outweighed by any significant improvement in clinical results.

Table 1

Advantages and Disadvantages of Anterior and Posterior Minimally Invasive Approaches to the Lumbar Spine

Approach	Advantages	Disadvantages
Anterior	Less soft-tissue dissection Less soft-tissue trauma and necrosis Less blood loss Improved cosmesis	Steep learning curve Possible limited exposure Increased surgical times (normalize with experience) Increased risk of retrograde ejaculation
Posterior	Less soft-tissue dissection Less blood loss Maintenance of posterior soft-tissue envelope (normal biomechanics) Surgical times similar to those of open techniques	Moderate learning curve Limited initial patient population until technically proficient Possible limited exposure

Patient Selection

There are too few data to determine the ideal patient who would benefit most from a minimally invasive approach to the lumbar spine. The indications for using a minimally invasive exposure should be partially based on the experience of the surgeon. For the surgeon at the beginning of the learning curve, the ideal patient would be one with moderate degenerative joint disease who requires single-level fusion at either L4-L5 or L3-L4, or a patient with a slim body habitus who presents with mild spondylolisthesis. The patient with more severe degenerative changes has associated anatomic changes that make these techniques more technically difficult.

As the surgeon becomes more proficient with minimally invasive techniques, additional indications could include multiple-level fusions and heavier patients. The patient with increased body mass index can be more difficult to treat because of the excessive soft tissue that needs to be traversed before reaching the spine. Once these techniques are mastered, however, the obese patient is a good candidate for minimally invasive fusion. Dilator tubes are often effective in holding the soft tissues out of the surgical field; without the dilator tubes, a more extensive incision and soft-tissue dissection would be required, as in the traditional open technique.

Summary

Lumbar spine fusion has undergone several modifications and advancements, which has led to the development of many new techniques and applications for an expanding list of conditions. Minimally invasive lumbar spine surgery is in its early years of development and analysis. Although there are many devices commercially available for minimally invasive spinal fusion, only devices evaluated in peer-reviewed literature were included in this review. As with any new technology, there is an associated learning curve and the possibility of unforeseen complications.

Many of the initial reports on minimally invasive lumbar spine surgery have shown similar clinical results with open surgical approaches in terms of spinal fusion rates. Currently, there is little evidence to suggest that the minimally invasive approach to anterior lumbar fusion is justified, considering the increased risk of complications, steep learning curve, and longer surgical times. With further developments, these techniques may become more commonplace. The data are more promising for minimally invasive posterior lumbar fusion than for anterior lumbar fusion. Although there are still associated learning curves with posterior approaches, results similar to those with open techniques have been achieved without significant increased risk or surgical times.

The individual surgeon must decide whether the time and effort needed to conquer the learning curve is justified by the potential benefits of minimally invasive spine procedures. For the field of spine surgery to grow and expand, there is a need for innovative individuals to move forward with new ideas and push beyond the current boundaries. Before minimally invasive techniques achieve widespread acceptance, prospective randomized trials are needed to better assess these new techniques and compare them with conventional open techniques.

Additional Resources

Related clinical topics article available on *Orthopaedic Knowledge Online:* "Bone Graft Alternatives in Spinal Fusion," by John M. Rhee, MD, and Scott D. Boden, MD.

Book: *Orthopaedic Knowledge Update: Spine 3,* edited by Jeffrey M. Spivak, MD, and Patrick J. Connolly, MD. Developed by the North American Spine Society.

CME Course: *Contemporary Techniques in Spinal Surgery 2007.* Course Directors, Frank M. Phillips, MD, and Sanford E. Emery, MD. November 8 to 10, 2007, Rosemont, IL.

References

Evidence-based Medicine: Reference 10 is a level I/II prospective randomized study. The remaining references are surgical technique descriptions, animal or biomechanical studies (level IV), and expert opinion (level V).

Citation numbers printed in **bold type** indicate references published within the past 5 years.

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