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Minimally Invasive Techniques for Lumbar Interbody Fusions

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Spinal fusions have been performed for nearly a century for a variety of conditions, such as for infections, trauma, deformity, degenerative conditions, and after resection for spinal tumors [1–11]. Typically, spinal fusions are performed as posterior/posterolateral or anterior for lumbar interbody arthrodesis. Traditionally, the ability to achieve adequate exposure to perform these procedures required an open surgical approach; however, with the advent of newer techniques and technology, combined with an improved understanding of surgical anatomy, newer minimally invasive techniques have been developed.

Some of the more common minimally invasive spine surgery (MISS) techniques being used for achieving lumbar interbody fusions are addressed. As such, the main posterior approach includes the transforaminal lumbar interbody fusion (TLIF), whereas anterior techniques include retroperitoneal and transperitoneal anterior lumbar interbody fusion (ALIF) approaches. In addition, other recent techniques are addressed, such as the extreme lateral interbody fusion (XLIF) and axial lumbar interbody fusion (AxiaLIF). The subsequent discussion includes a general review of the history, indications, brief overview, and description of each surgical technique.

History

The first description of lumbar interbody fusion was published in the 1930s by Capener and colleagues [12]. The original technique was described as an anterior approach for treatment of spondylolisthesis of the lumbar spine. A complete discectomy was performed, and the listhetic segment was reduced using a structural cadaveric bone graft with supplemental autograft as an ALIF. Subsequently, in the 1950s, Cloward [5] described a technique for performing a lumbar interbody fusion through a posterior laminectomy, which became known as a posterior lumbar interbody fusion (PLIF). In the original description, the PLIF procedure was designed to preserve the facet joints and required nerve root retraction to allow for adequate disc excision and placement of the interbody graft or cage. In the attempt to reduce the risk for nerve root injury and irritation and provide enhanced visualization of the intervertebral disc, the TLIF approach was described [13,14]. In the ensuing years, an extreme lateral/transpsoas approach to the spine has been reported for XLIF procedures [15]. In this

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technique, access to the lumbar spine is achieved by a lateral approach that passes through the retroperitoneal fat and psoas major muscle. Theoretically, this approach avoids the potential complications associated with an anterior retroperitoneal and transperitoneal approach to the lumbar spine, thereby avoiding the major vessels that typically are encountered with the traditional ALIF approaches. More recently, a percutaneous approach to the anterior lumbosacral spine that uses the presacral space has been described [16–18].

Indications

The indications to proceed with a minimally invasive lumbar interbody fusion are similar to the indications to proceed with an open lumbar interbody fusion. Although the indications vary slightly from surgeon to surgeon and from patient to patient, in most cases, the decision to proceed with an interbody fusion includes evidence of preoperative segmental instability, stenosis with deformity that may result in progressive deformity after decompression, wide decompressions that may result in iatrogenic instability, and possibly in patients who have recurrent disc herniations [19,20].

Surgical techniques

Transforaminal lumbar interbody fusion

Overview, advantages, and disadvantages

Originally described by Blume and Rojas [13] and popularized by Harms and colleagues [14], the TLIF is an adaptation of the PLIF technique first described by Cloward [5]. Because the TLIF uses a unilateral approach to the disc space through the intervertebral foramen, it confers several theoretical advantages. First, because it uses the more common posterior approach, this technique is more familiar to most spine surgeons. The TLIF provides access to the posterior elements and the intervertebral disc space, thereby allowing the surgeon the ability to achieve a circumferential fusion [21–24]. Second, because the contralateral facet and posterior laminar arch typically are preserved, especially when using MISS techniques, there is a theoretical lower risk for adjacent segment disease, while essentially eliminating iatrogenic contralateral scar formation compared with the more traditional bilateral PLIF approach [25–27]. Furthermore, because the approach uses a unilateral facetectomy, it provides exposure of the disc space while requiring less dural retraction; however, if excessive facet removal is performed, segmental stability may be compromised [28]. In such cases, segmental pedicle screw or translaminar screw fixation also is performed to enhance segmental stability. Lastly, this approach allows the surgeon to address posterior element pathology (eg, spinal stenosis, lateral recess and foraminal stenosis, synovial cysts, hypertrophic ligamentum flavum) concurrently with an interbody fusion through a single posterior incision.

Surgical technique: transforaminal lumbar interbody fusion

Following induction of general endotracheal anesthesia and administration of preoperative antibiotics, the patient is positioned prone on a radiolucent table. If possible, the use of a radiolucent table with the capability for left and right rotation is used. If desired, after positioning, on-table anteroposterior (AP) and lateral fluoroscopic images can be obtained to ensure adequate intraoperative image capture. True AP and lateral images of the interspace, vertebral bodies, and pedicles of interest should be visualized adequately to ensure accurate and safe placement of the interbody graft and subsequent pedicle screws (Fig. 1A, B). Once it is confirmed that adequate imaging can be obtained, the patient is prepped and draped in the usual sterile fashion.

The midline is identified by palpating the spinous process. Fluoroscopy is used to locate the appropriate levels. After needle localization, a longitudinal incision is made approximately 2.5 to 3.5 cm lateral to the midline on the affected side that is approximately 2.0 to 2.5 cm in length. The incision is deepened through the skin down to the fascia. The fascia is divided carefully to accommodate the dilators. After confirmation of the appropriate level, the initial introducer is docked at the facet/laminar junction of interest, and dilators of increasing diameter are inserted sequentially. The appropriate depth is noted after the last diameter of interest is inserted. At this point, the tubular retractor of the appropriate diameter, typically 18 to 25 mm in diameter and depth, is selected (Fig. 1C). Depending on the surgeon's preference, the rest of the procedure is performed with the operative microscope or with loupe magnification. Intermittent fluoroscopic images are obtained throughout the surgical

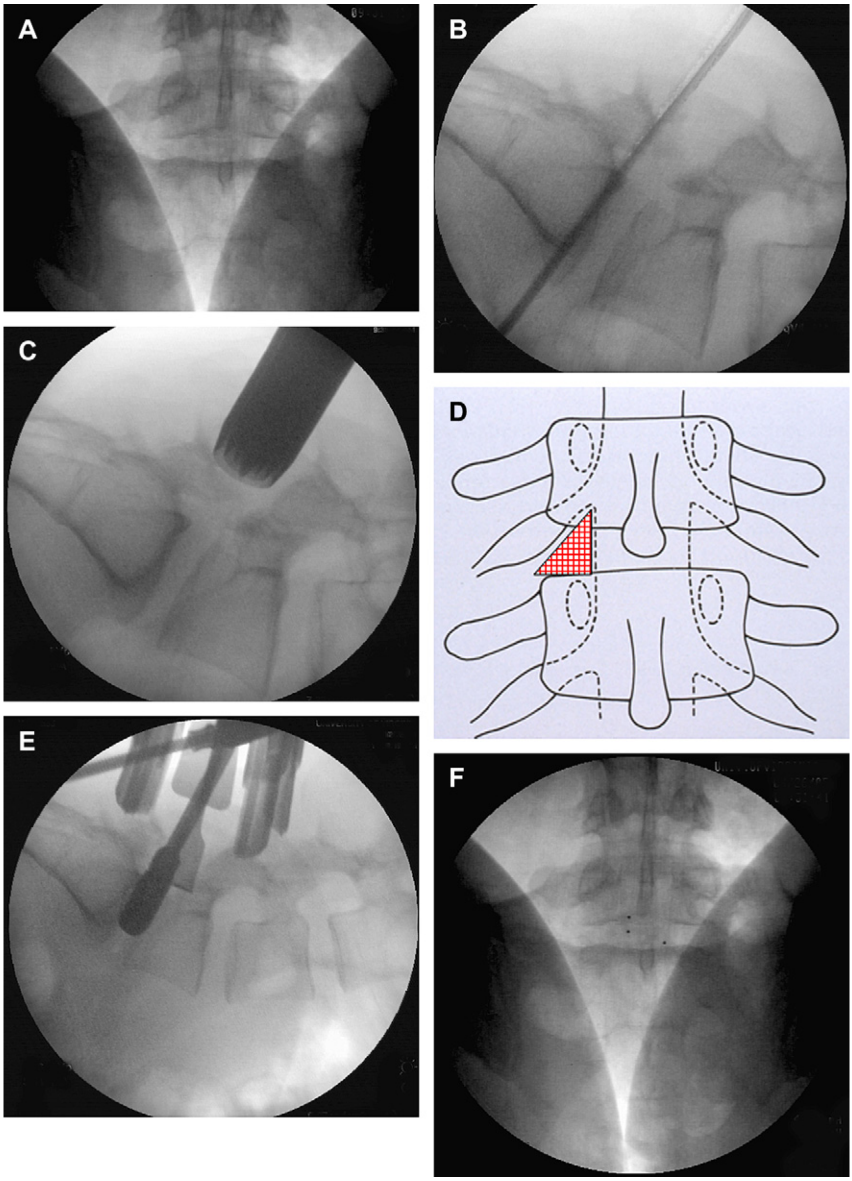

Fig. 1. Intraoperative fluoroscopic images of the intervertebral disc of interest demonstrating an AP (*A*) and lateral (*B*) image. (*C*) Lateral intraoperative fluoroscopic image with the tubular retractor docked at the level of interest. Note that the tubular retractor is in line with the intervertebral disc of interest. (*D*) Working corridor for the TLIF bordered by the thecal sac medially, the exiting nerve root superiorly, and the pedicle wall inferiorly. (*E*) Insertion of a trial spacer before final cage placement can assist in (*F*, *G*) determining final implant dimensions. Note that the margins of the interbody cage are marked with three radiopaque beads to allow for radiographic determination of the final position of the implant. AP (*H*) and lateral (*I*) fluoroscopic images following a TLIF and placement of the percutaneous pedicle screws.

procedure as needed to help assist in localization and ensure accurate placement of the spinal instrumentation.

At this point, the tubular retractor is docked on the facet joint complex, and a total facetectomy is performed using a combination of osteotomes, Kerrison rongeurs, and a high-speed burr. Complete resection of the inferior articular facet of the superior vertebral and superior articular facet of the inferior vertebra

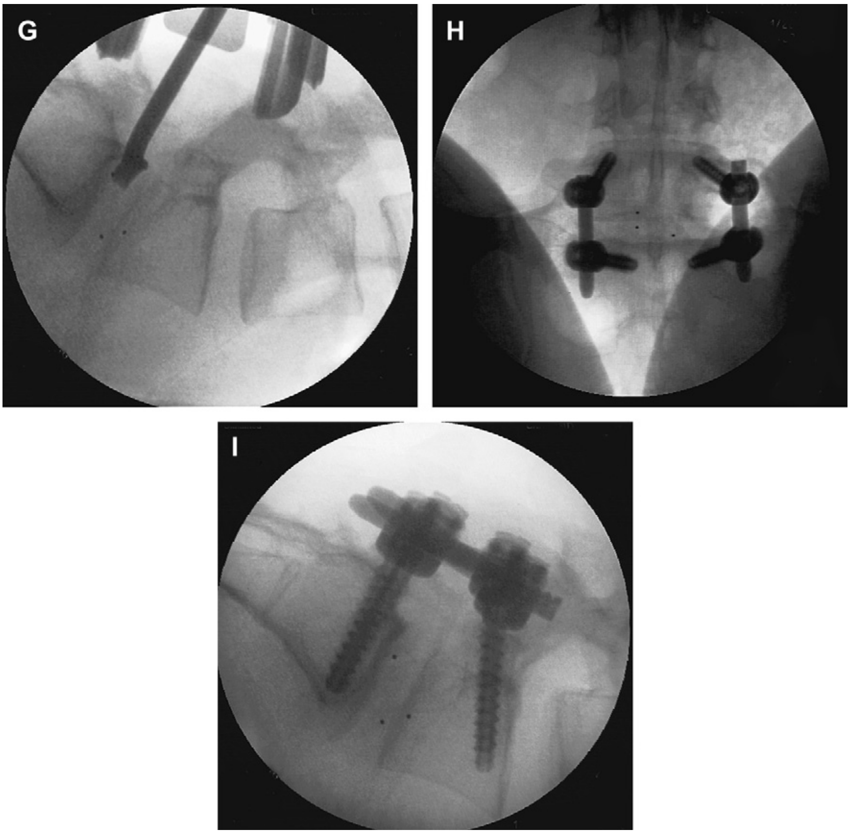

Fig. 1 (*continued*)

completes the "access." This portion of the surgery helps to distinguish it from other surgical approaches. By performing a total facetectomy, it places the operative "corridor" to the intervertebral disc through the neuroforamen or transforamen. Therefore, the working corridor is the space defined by the common thecal sac medially, exiting nerve root superiorly, and pedicle wall inferiorly (Fig. 1D). The advantage conferred by this approach is that there is less medial retraction of the traversing nerve root. Care should be taken to protect the exiting and traversing nerve root during the remainder of the surgery.

At this time, the annulotomy and discectomy are completed as per the surgeon's standard technique. Care should be taken to perform as complete a total discectomy as possible. The use of sequential dilators and endplate shavers can help to facilitate the discectomy and allows for sequential dilation of the intervertebral disc space. Although the cartilaginous endplates should be removed, care should be taken to avoid excessive removal of the bony portion of the endplates and the subchondral bone to reduce the risk for graft subsidence [14,29].

Once the discectomy is completed and the endplates have been prepared, the interbody fusion is performed by packing the interspace with morselized cancellous bone graft, autologous local bone, or structural allograft. If morselized cancellous bone is used, the use of a structural cage device may help to provide structural support, realign the sagittal lumbar contour, and restore neuroforaminal height. Trial spaces can be inserted to help determine ideal cage dimensions (Fig. 1E) before placement of the final implant (Fig. 1F, G). The use of autologous iliac crest may provide additional bone graft material if needed.

Although the TLIF approach typically is performed unilaterally, the complete resection of the superior and inferior articular process of the corresponding inferior and superior vertebra may be performed, resulting in segmental instability. As a result, the lumbar interbody fusion typically is combined with percutaneous or limited open screw fixation (Fig. 1H, I). These options are described more fully elsewhere in this issue. The incisions are closed in the standard technique after copious irrigation. Typically, the use of a closed suction drain is unnecessary.

Limited open anterior lumbar interbody fusion

Overview, advantages, and disadvantages

Originally, ALIF was described for the surgical management of Pott's disease of the spine [1]. In 1932, Capener [30] was the first to describe the use of ALIF for the treatment of spondylolisthesis. Since that time, the indications for the use of ALIF have expanded to include degenerative disc disease, infections, instability, deformity, and posterior pseudarthrosis [31,32]. Unfortunately, the subsequent description by Harmon [33] in 1960, involved a more traditional extensile left extraperitoneal approach that was criticized and believed to be too traumatic to patients [34].

Since the initial description of the ALIF, several reports have demonstrated good results. The technique has been modified with minimally invasive techniques in mind, thereby using smaller incisions combined with muscle-splitting approaches [35–37]. Although the use of laparoscopic approaches also has been well described and have good to excellent results when used for the appropriate patient and pathology, its steep learning curve and highly technical nature have prevented its widespread use and acceptance among spine surgeons.

The greatest advantage of the ALIF technique may be the direct access and visualization of the intervertebral disc space [35–37]. As a result, it is generally accepted that the ability to achieve a more complete discectomy, and theoretically a better fusion, typically is greater with ALIF than with TLIF, XLIF, or AxiaLIF techniques. Furthermore, compared with TLIF, ALIF does not violate the posterior musculature or bony elements and does not require nerve root retraction or typically necessitate entering into the spinal canal.

Several disadvantages are associated with the ALIF technique. If supplemental posterior instrumentation or a posterior decompression is required, a separate posterior incision and surgical approach must be performed. Moreover, the anterior approach mobilizes the great vessels and the peritoneal contents, placing them at risk for iatrogenic injury [38]. In addition, iatrogenic injury to the superior hypogastric sympathetic plexus during the anterior approach to the lumbosacral junction can result in retrograde ejaculation in men [39–41].

Surgical technique: retroperitoneal anterior lumbar interbody fusion

Following induction of general endotracheal anesthesia and administration of preoperative antibiotics, the patient is positioned in the left side up, right lateral decubitus position on a radiolucent table. If possible, the table should be flexed at the interspace of interest. This physically increases the distance between the iliac crest and rib cage, thereby facilitating access to the spine, and it allows for distraction of the intervertebral disc to help facilitate the discectomy (Fig. 2A).

After positioning on the operative table, the patient is prepped and draped in the usual sterile fashion. Although not required for this approach, intraoperative fluoroscopy—to help localize the intervertebral disc of interest—can be used to assist in the placement of the surgical incision. Transverse, horizontal, and oblique incisions have been described and can be selected based on the surgeon's preference.

The skin is incised, and the anterior abdominal musculature can be divided in line with the skin incision or preserved with blunt dissection by carefully splitting each layer (external oblique, internal oblique, and transversus abdominus) in line with its corresponding fibers. Although not always possible, care should be taken to avoid perforating the peritoneum. After passing through the fascia and accessing the retroperitoneal space, the peritoneum is gentle swept anteriorly, typically carrying the abdominal contents and the ureter safely away from the surgical site. The dissection is carried bluntly down to the medial border of the psoas muscle.

The psoas muscle attachments are carefully dissected off the lateral border of the intervertebral disc. To reduce the risk for lumbar nerve root irritation or injury, the dissection should not be extended posterior to the neuroforamen and pedicle entrance [42]. If necessary, however, branches of the sympathetic chain can be identified and cauterized to achieve better exposure. In addition, care should be taken not to injure the genitofemoral nerve, which lies on the anterior

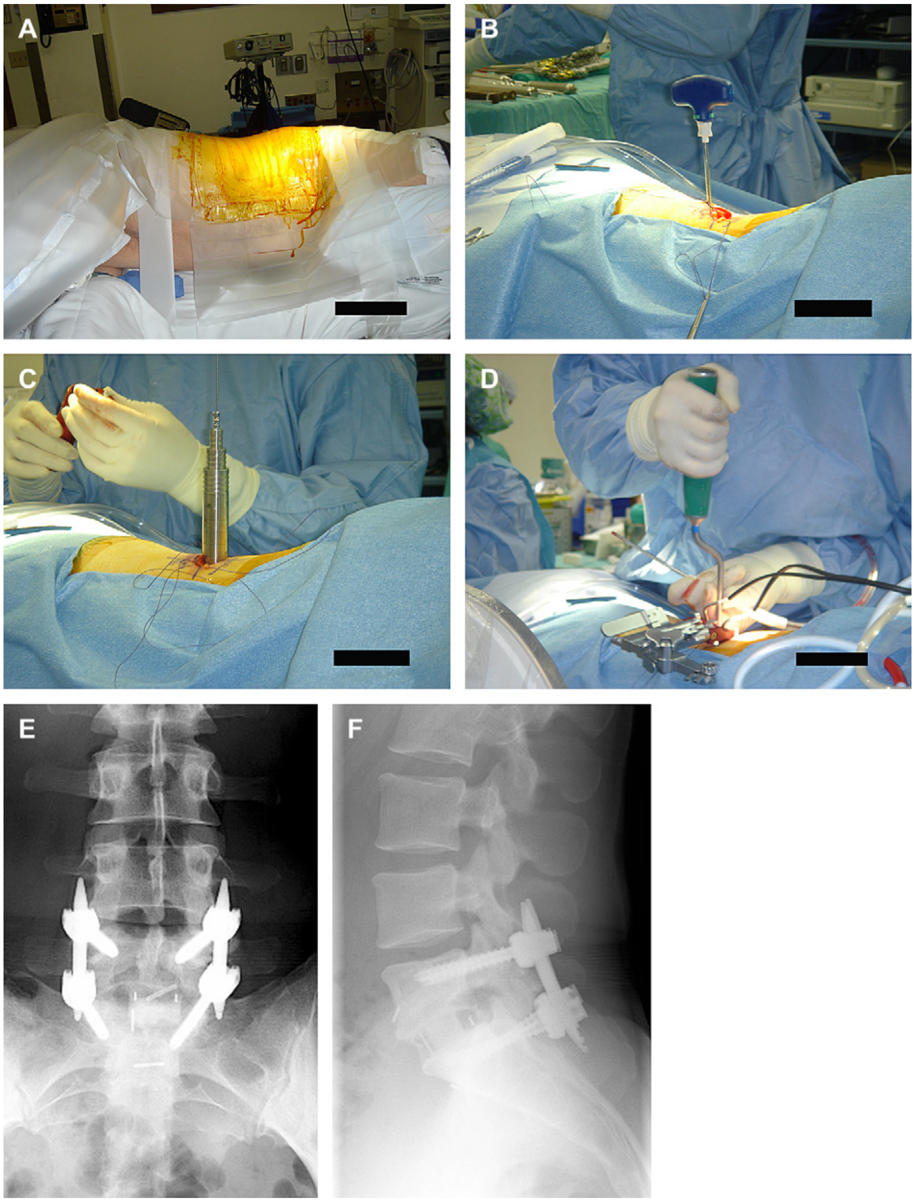

Fig. 2. (*A*) Intraoperative photograph demonstrating the lateral decubitus position. Intraoperative photographs demonstrating confirmation of the intervertebral disc space of interest (*B*) with subsequent placement of the sequential dilators (*C*). (*D*) Intraoperative photograph demonstrating the use of a bayoneted trial through a MISS retractor. Postoperative AP (*E*) and lateral (*F*) plain radiographs of a L5–S1 transperitoneal ALIF with percutaneous pedicle screw fixation.

surface of the psoas. Once the anterior and lateral borders of the intervertebral disc are identified and the level has been confirmed on fluoroscopy, the standard radiolucent retractor system blade or a tubular retractor system can be inserted and docked onto the intervertebral disc space (Fig. 2B, C).

A discectomy can now be performed under direct vision using standard instrumentation. A thorough discectomy and endplate preparation are performed to increase the interbody fusion rate. As in the other approaches, the bony endplate and subchondral bone are largely preserved to reduce the risk for excessive graft subsidence [16,31,43]. Interbody distraction and careful implant placement can help to restore coronal and sagittal plane imbalance. The use of bayoneted instrumentation may help to facilitate placement of the implant (Fig. 2D). The interbody fusion is completed by packing the interspace with morselized cancellous bone graft or structural allograft. If morselized cancellous bone is used, a structural cage device may help to provide structural support, realign the sagittal lumbar contour, and restore neuroforaminal height. Autologous bone graft harvested from the iliac crest may provide additional graft material. The decision to add instrumentation should be individualized to the patient based on bone quality, local anatomy, and indications for surgery.

Following copious wound irrigation, the incision is closed in the standard technique. Typically, the use of a closed suction drain is unnecessary. The patient is positioned prone for placement of percutaneous or limited open screw fixation. These options are described more fully elsewhere in this issue.

Surgical technique: transperitoneal anterior lumbar interbody fusion for L5–S1

Following induction of general endotracheal anesthesia and administration of preoperative antibiotics, the patient is positioned supine on the operating table. If necessary, the table can be hyperextended to allow for improved access to the L5–S1 interspace. Depending on the surgeon's choice, a transverse (Pfannenstiel's) or vertical surgical incision can be used.

The skin and superficial fat are divided in line with the incision. The peritoneum is reached by sharply dissecting the linea alba and ligamentum urachi in the midline. A muscle spreader is inserted to improve visualization of the peritoneal contents. The abdominal contents are protected by packing them into the superior portion of the abdominal cavity using laparotomy pads; this may be facilitated by placing the patient in the Trendelenburg position.

The deep retractors are placed carefully to allow for exposure of the promontorium, common iliac artery, and ureter, which, in a previously unoperated case, lie within the retroperitoneum coursing over the common iliac artery. A vertical incision in the parietal peritoneum is made carefully, approximately 5 mm medial to the right common iliac artery, to obtain access to the retroperitoneal space. The retroperitoneal fat with the superior hypogastric plexus is exposed and retracted carefully to the left by blunt dissection with cottonoid patties. To reduce the risk for damage to the superior hypogastric plexus, electrocautery should be performed sparingly; when necessary, bipolar coagulation should be used. The middle sacral artery and vein are exposed, tied, and ligated as necessary.

Once the L5–S1 intervertebral disc is exposed, the annulotomy and discectomy are completed as per the surgeon's standard technique. Care should be taken to perform as complete a total discectomy as possible. The use of sequential dilators and endplate shavers can help to facilitate the discectomy and allow for sequential dilation of the intervertebral disc space. Although the cartilaginous endplates should be removed, care should be taken to largely preserve the bony portion of the endplates and the subchondral bone to reduce the risk for excessive graft subsidence [16,31,43].

The remaining fusion can be completed by packing the interspace with morselized cancellous bone graft or structural allograft. If morselized cancellous bone is used, a structural cage device may help to provide structural support, realign the sagittal lumbar contour, and restore neuroforaminal height (Fig. 2E, F). The use of autologous iliac crest may provide additional bone graft material if needed.

The application of an anterior buttress plate or interference screw with a washer can provide additional stability in cases where graft dislodgment or additional structure support are required. This decision should be individualized to each patient and specific pathology being addressed. The laparotomy pads are removed, and the incision is closed in the standard technique after copious irrigation. Typically, the use of a closed suction drain is typically unnecessary.

Extreme lateral interbody fusion

Overview, advantages, and disadvantages

Because many of the complications of ALIF are associated with the surgical exposure, alternative approaches have been investigated. In 1998, McAfee and colleagues [35] described a minimally invasive, endoscopic anterior retroperitoneal approach to the lumbar spine that did not enter into the peritoneum or require anterior dissection near the great vessels. Because the trajectory of the approach was anterior to the psoas muscles, and the technique required a considerable amount of retraction of the muscle posteriorly, there frequently was significant muscle swelling and weakness after surgery. As a result, an extreme lateral endoscopic transpsoas approach was developed to address some of these issues [44,45].

There are many advantages of the XLIF over the more traditional ALIF approach. The lateral approach does not require a general surgeon for access and eliminates the need to enter into the peritoneum or to retract the great vessels; however, there are limitations associated with the XLIF technique. The anatomic location of the ribs and of the iliac wing can limit the exposure to L1–2 down to L4–5. Frequently, the ability to expose and address L5–S1 safely or adequately can be limited by the superior edge of the iliac crest [15]. Furthermore, at L5–S1, dissection within the substance of the psoas major, even when done carefully, places the nerves of the lumbar plexus at risk. Direct surgical trauma to the psoas major itself can result in weakness.

The use of intraoperative electromyographic (EMG) monitoring has been recommended to help reduce the potential risk for nerve root injury [46]. In addition, dissecting predominantly within the anterior one third to one half of the psoas major also can reduce the risk for nerve root injury [15,31,33,45]; however, this clearly decreases the surgeon's ability to perform a more complete discectomy and address pathology within the posterior aspect of the intervertebral disc and directly manage intracanal pathology. Indirect foraminal decompression is possible by restoring the neuroforaminal height and sagittal alignment during the interbody fusion. The decision to include posterior spinal fusion or instrumentation should be individualized to the patient and pathology being addressed.

Surgical technique: extreme lateral interbody fusion

Following induction of general endotracheal anesthesia and administration of preoperative antibiotics, the patient is positioned in the left side up, right lateral decubitus position on a radiolucent table. If possible, the table should be flexed at the interspace of interest (Fig. 3A). This helps to open the intervertebral disc to facilitate the discectomy and helps to increase the distance between the iliac crest and rib cage.

After positioning on the operative table, the patient is prepped and draped. AP and lateral fluoroscopic images are obtained. Using a radiopaque marker, the center of the affected disc is localized on the lateral radiograph (Fig. 3B, C). A corresponding location is marked on the skin, representing the site for the skin incision to be used. Care should be taken to ensure that the approach to the intervertebral disc of interest is not affected by the ribs or iliac wing. This is particularly important if consideration is being undertaken to address the L5–S1 interspace through an XLIF approach.

The skin is incised. As in the anterior retroperitoneal approach for ALIF, the anterior abdominal musculature can be divided in line with the skin incision or preserved with blunt dissection by carefully splitting each muscular layer in line with its corresponding fibers. If possible, care should be taken to avoid entering into the peritoneum. After passing through the fascia and accessing the retroperitoneal space, the peritoneum is gentle swept anteriorly and the dissection is carried bluntly down to the psoas muscle.

Based on the surgeon's preference, the standard radiolucent retractor system blade or a tubular retractor system can be inserted and docked on the lateral border of the psoas directly over the intervertebral disc space to be addressed, as confirmed by AP and lateral fluoroscopy. The muscle fibers are separated gently with blunt dissection through the psoas (Fig. 3D). Unlike the anterolateral approach used for ALIF, the direct lateral approach through the psoas theoretically reduces the risk for injury to the great vessels, because they remain anterior to the operative corridor [15,31,33,45]. Because the approach traverses the psoas, however, the nerves of the lumbosacral plexus and the psoas itself are at some risk for injury. Staying within the anterior third of the psoas and the use of EMG monitoring can help to reduce the risk for injury to the lumbar plexus, which lie more posteriorly within the psoas major. In addition, care should be taken not to injure the genitofemoral nerve, which lies on the anterior surface of the psoas.

The dissection through the psoas is performed carefully until the surface of the disc is reached. Because the nerves are not visualized directly, the use of EMG during this portion of the approach will help the surgeon to identify the presence of the nerve. Once the final position has been obtained, it should be reconfirmed by fluoroscopy. At this point, subsequent dilators are inserted until the final diameter is reached and the corresponding retractor system of the appropriate depth is inserted. The size of the exposure should be adjusted according to the needs of the surgeon and the pathology to be addressed.

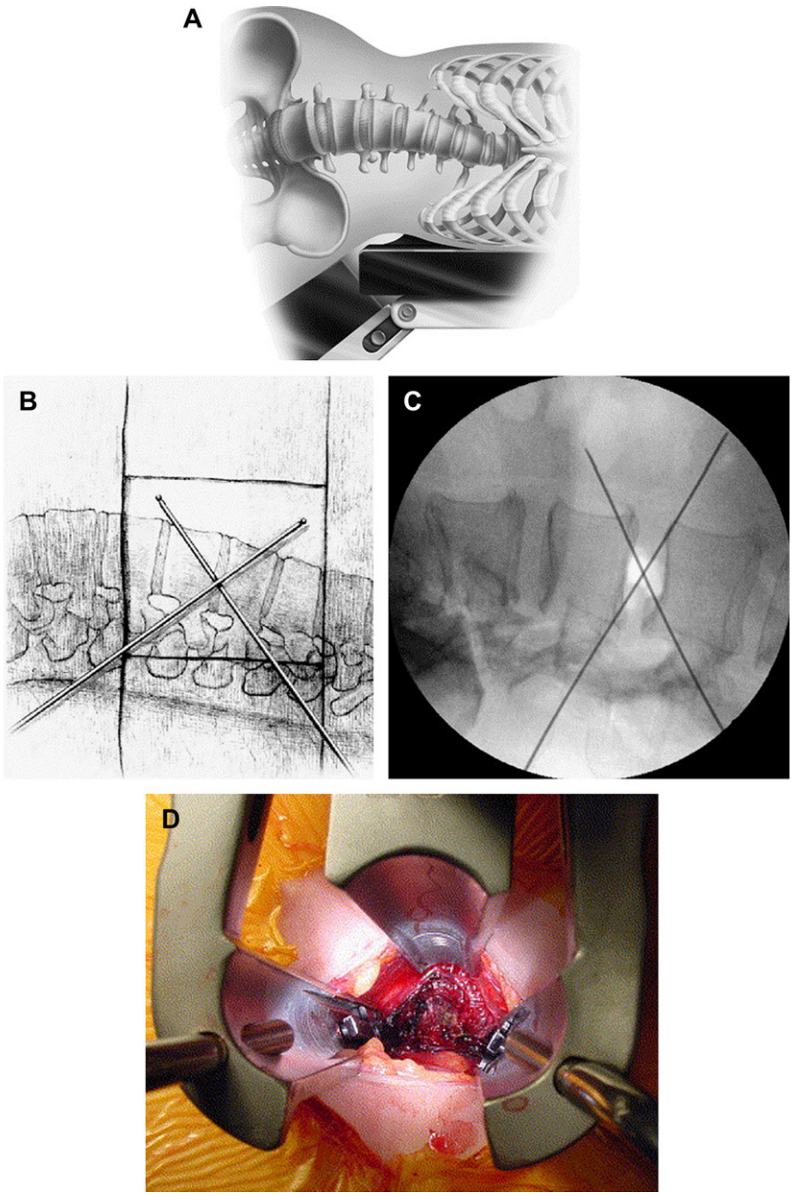

Fig. 3. (*A*) The lateral position with the operative table flexed at the interspace of interest. Schematic (*B*) and lateral (*C*) fluoroscopic image demonstrating intraoperative localization of the intervertebral disc of interest. (*D*) Intraoperative image looking down the retractor system, which is placed in the lateral position. The transpsoas approach has been completed, and the retractor system is docked on the interspace of interest. (*A-D*) (*From* Ozgur BM, Aryan HE, Pimenta L, et al. Extreme lateral interbody fusion (XLIF): a novel surgical technique for anterior lumbar interbody fusion. Spine J 2006;6:437,440; with permission.) AP (*E*) and lateral (*F*) preoperative radiographs demonstrating degenerative scoliosis with loss of lumbar lordosis. Preoperative right (*G*) and left (*H*) benders help to determine the levels necessary for release, fusion, and instrumentation. (*I*, *J*) Plain radiographs after anterior releases and structural interbody grafts placed at L3–4 and L4–5 from an XLIF approach addressing the concavity of the curve. Percutaneous pedicle screw fixation was performed at the same surgical sitting. The postoperative plain radiographs demonstrate restoration of the coronal alignment and restoration of a more normal lumbar lordosis.

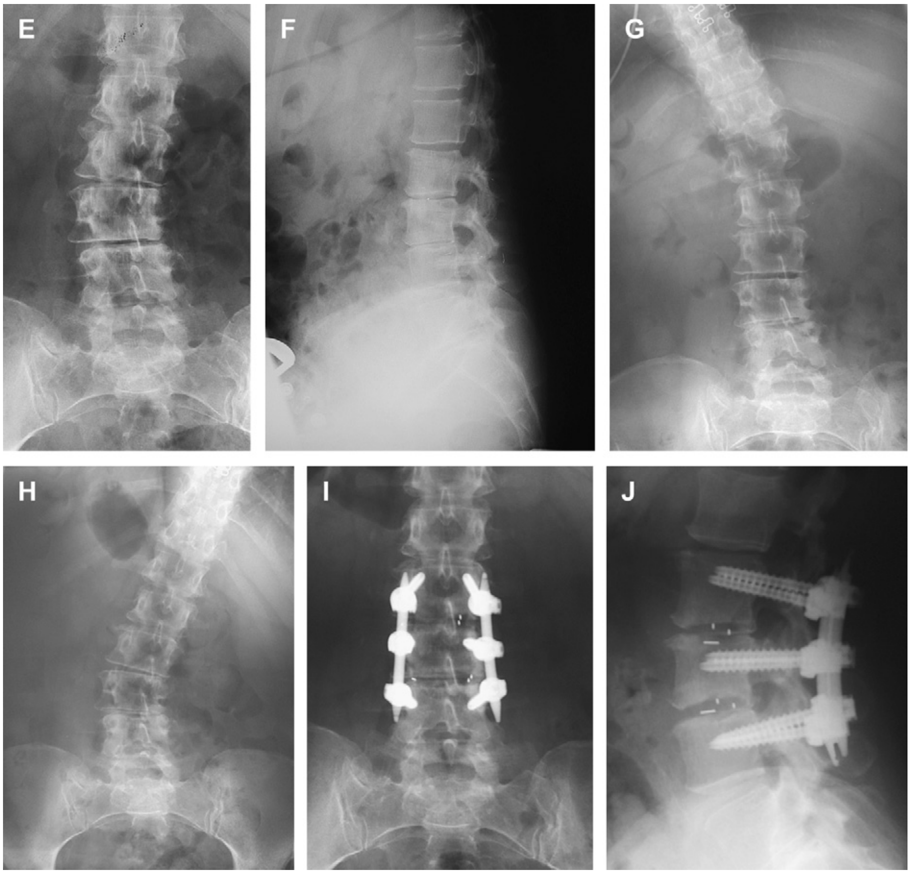

Fig. 3 (*continued*)

A discectomy can now be performed under direct vision through the "corridor" developed using standard instrumentation. The annulotomy is created in the anterior half of the intervertebral disc. Typically, the posterior annulus is left intact; however, if necessary, the contralateral annulus can be released with a Cobb elevator. Care should be taken to ensure that the intraoperative positioning of the patient has not shifted during the initial dissection. Iatrogenic nerve or vascular injury can occur if unrecognized shifts in patient positioning have occurred.

A thorough discectomy and endplate preparation are performed to increase the interbody fusion rate. As in the other approaches, bony endplate and subchondral bone removal should be kept to a minimum to reduce the risk for excessive graft subsidence [15,31,33,45]. Interbody distraction and careful implant placement can help to restore coronal and sagittal plane imbalance (Fig. 3E–H). The interbody fusion is completed by packing the interspace with morselized cancellous bone graft or structural allograft. If morselized cancellous bone is used, a structural cage device may help to provide structural support, realign the sagittal lumbar contour, and restore neuroforaminal height (Fig. 3I, J). If needed, additional bone graft material can be harvested from the autologous iliac crest.

The incision is closed in the standard technique after copious irrigation. Typically, the use of a closed suction drain is unnecessary. The patient is positioned prone for placement of percutaneous or limited open screw fixation. These options are described more fully elsewhere in this issue.

Axial lumbar interbody fusion

Overview, advantages, and disadvantages

Disadvantages and limitations of anterior, posterior, and direct lateral approaches to the lumbar spine have resulted in the development of techniques to address the spine axially (perpendicular to the vertebral endplate along the long axis of the spine). Conceptually, interbody fusions with instrumentation placed along the long axis of the spine have appeal from a biomechanical standpoint because of the ability to place instrumentation close to the bending axis of the spine and in line with the compression moments of the vertebral bodies [16–18]. This has been recognized for years, and— although not a new concept—para-axial open approaches to the lumbosacral spine have been described through the use of a fibular strut graft from L5 to S1. A true axial approach to the lumbosacral spine has been limited by the availability of appropriate techniques and implants.

Recently, based upon a series of cadaveric studies and carefully designed clinical studies, a percutaneous access method for addressing the anterior lumbosacral spine has been described. The L5–S1 disc space is accessed through the presacral space through a minimally invasive incision (Fig. 4A) [16–18]. Because this technique avoids dissection anterior, posteriorly, and laterally to the spine, it does not result in injury and disruption of the posterior musculature, ligaments, or elements. Similarly, it does not require entering into the abdominal cavity nor mobilization or retraction of the vasculature or intra-abdominal viscera.

Because the sacrum is separated from the rectum by the mesorectum and covered by the visceral fascia, typically, this plane is easy to develop bluntly once it is correctly identified [18]. Although this presacral anatomy is more familiar to general and colorectal surgeons, it is not as comfortable an approach for the spine surgeon. Like any surgical approach, it is critical that the operating surgeon has a thorough understanding of the presacral anatomy to reduce the risk for injury to the surrounding structures. Potential complications continue to be associated with inadvertent injury to the surrounding structures; however, newer implants and surgical techniques, combined with the use of biplanar fluoroscopy, are imperative to reduce the risk for iatrogenic complications. Concerns regarding infections secondary to the paracoccygeal approach and microperforations to the rectum have not been realized; however, because clinical experience with this technique is limited, complication rates are unknown.

Other concerns include the increased need for intraoperative fluoroscopy during this AxiaLIF technique to ensure proper midline surgical approach and implant trajectory. Lastly, evacuation of the intervertebral disc is performed with special instrumentation performed only with fluoroscopic guidance. Therefore, the surgeon is unable to address intracanal pathology or visualize the discectomy directly.

Surgical technique: axial lumbar interbody fusion

Following induction of general endotracheal anesthesia and administration of preoperative antibiotics, the patient is positioned prone on a radiolucent table. In selected cases, if improved visualization and localization of the rectum is required during lateral fluoroscopy, a 20F catheter may be inserted into the rectum and the balloon insufflated. The anus is isolated from the planned surgical field with an occlusive dressing. Before the formal prep and drape, fluoroscopy can be brought into the surgical field to confirm the ability to achieve adequate AP and lateral images. Once this is confirmed, the sacrococcygeal and gluteal regions are prepped and draped in the usual sterile fashion.

Next, the paracoccygeal notch is palpated and a 15- to 20-mm incision is made lateral to the coccyx. The skin and underlying fascia are incised carefully. The superficial tract is confirmed and opened gently with blunt finger dissection. The guide pin introducer assembly is inserted into the incision and advanced gently along the anterior midline of the sacrum (Fig. 4B). Using tactile feedback and fluoroscopic guidance, using a slow sweeping movement, continuous bony contact is maintained between the introducer tip and the anterior sacrum. This allows for careful development of the presacral space.

Use of intraoperative fluoroscopy in the AP and lateral projections is imperative to ensure that the trajectory of the introducer tip remains in the midline and within the presacral space on the anterior sacral surface. Inadvertent passage of the introducer tip from this path places the nerves exiting the neural foramen more laterally and the anterior pelvic structures (eg, rectum and middle sacral artery) at increased risk for injury. Next, under fluoroscopic guidance, the introducer is docked on the anterior cortex of the sacrum at the junction of the S1 and S2 vertebral bodies.

The blunt guide introducer is exchanged for the sharp guide pin. The trajectory of the guide pin is confirmed to be as near the midline as possible as it passes through the L5–S1 disc space on the AP view. Similarly on the lateral

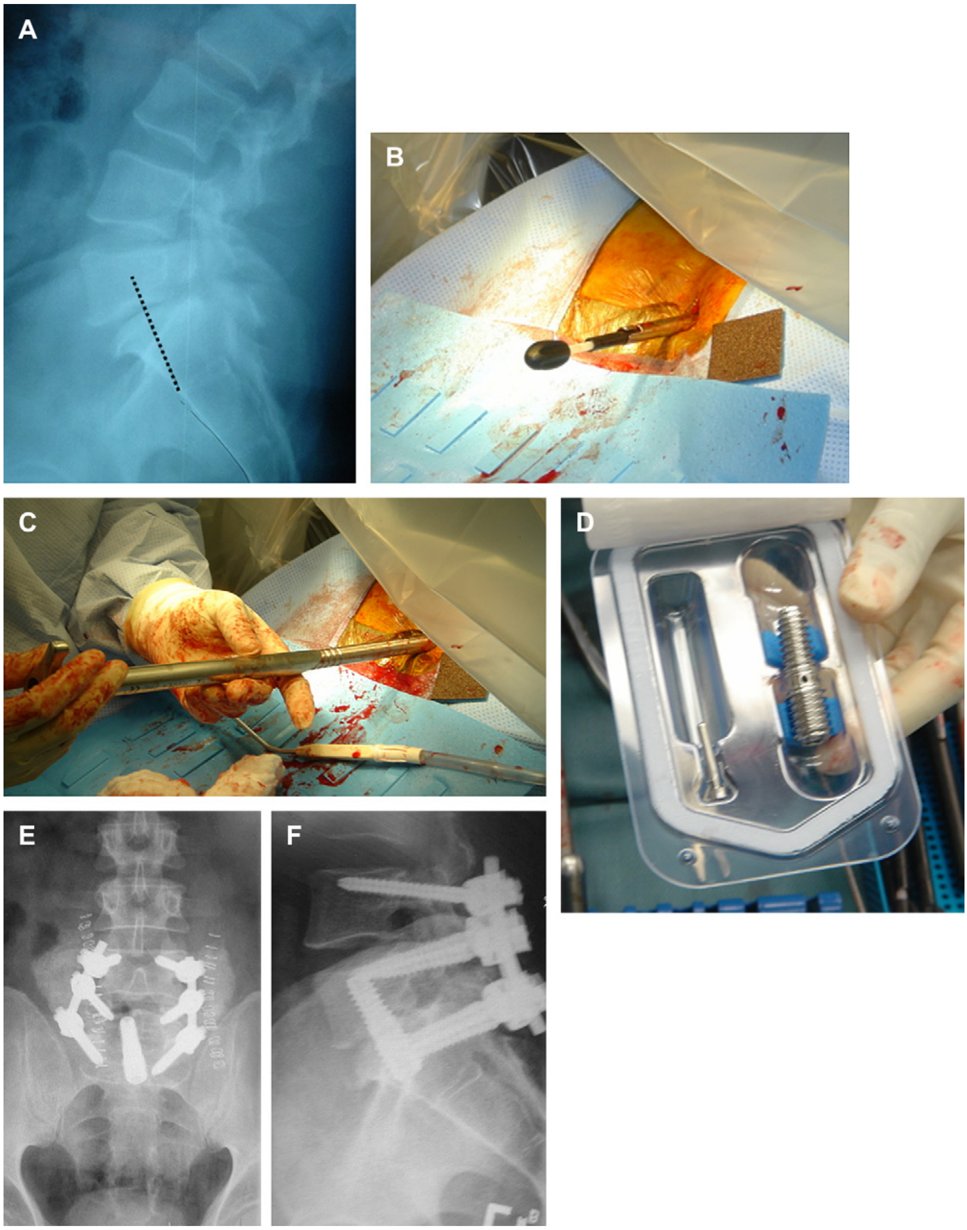

Fig. 4. (*A*) Preoperative lateral plain radiograph addressing the L5–S1 interspace through an AxiaLIF approach using the presacral space. (*B*) Intraoperative photograph demonstrating the introducer assembly inserted through a small paramedial incision. (*C*) Intraoperative photograph demonstrating the final dilator sheath in place. (*D*) Photograph demonstrating the differential pitch of the AxiaLIF threaded rod, which allows for distraction across the disc space during intraoperative insertion. AP (*E*) and lateral (*F*) postoperative radiographs of the AxiaLIF threaded screw in place addressing the L5–S1 interspace with corresponding L4–S1 pedicle screw fixation.

fluoroscopic image, the trajectory should pass through the middle portion of the L5–S1 disc space and end in the middle or anterior portion of the L5 vertebral body. The guide pin is tapped gently into the sacrum along the planned path using a cannulated slap hammer. The guide pin extension is attached, and sequential dilators are used to dilate the presacral soft tissue and create the osseous working channel within the sacrum. Once this is completed, the final dilator sheath is advanced and anchored to the sacrum creating the transsacral working corridor (Fig. 4C).

Thereafter, a threaded reamer is advanced through the sacrum and intervertebral disc until it comes to rest on the inferior endplate of L5. The inferior endplate of L5 is preserved and not perforated by the threaded reamer. The reamer is removed, and the bone from the reamer is saved as autologous bone grafting.

Following, using specially designed cutting-loop devices and disc extractors, the discectomy is performed at L5–S1 under fluoroscopic guidance. Next, the bone graft material of choice is packed directly into the disc space. Using a 7.5-mm drill, the L5 vertebral body is penetrated and advanced to within 1 cm of the superior endplate of L5. The final guide pin is inserted, followed by the titanium-threaded rod. Because the threaded rod is specially designed with differential thread diameter and pitch, this allows for distraction across the disc space as it is inserted, thereby restoring the intervertebral disc and neuroforaminal height (Fig. 4D).

The threaded rod is inserted slowly under fluoroscopy until it is firmly seated under the superior endplate of L5. Because the implant is designed with a center channel and exterior ports, an injection portal can be docked onto the threaded rod and additional bone graft material may be added, which will exit within the intervertebral space. The injection portal is disengaged, and the threaded rod is sealed with a threaded plug to prevent graft extrusion. The introducer cannula is removed. The incision is irrigated and closed in the standard fashion. The addition of percutaneous pedicle screw fixation is performed in the standard technique (Fig. 4E, F).

Summary

The indications to proceed with a minimally invasive interbody fusion are similar to the indications for pursuing an open spinal fusion. Each surgical technique outlined above carries benefits and risks inherent to the surgical approach, the surrounding structures, and its ability to address various anatomic lesions. Therefore, each technique should be considered in the context of the surgeon's personal experience and technical abilities and be individualized to the patient's specific pathology. In the properly selected patient, newer minimal invasive surgical approaches—combined with advanced surgical techniques and implants—may reduce surgical morbidity, decrease the postoperative recovery time, and increase the early postoperative rehabilitation potential.

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