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Orthopaedics

LLIF as a Less Invasive Adjunct for Deformity Surgery

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Adult spinal deformity is a complex spectrum of disorders that commonly results in symptomatic spinal stenosis and decreased quality of life in patients over 60. Correction of severe deformity remains a challenge for even the most experienced surgeons. This challenge is amplified in patients over 60, where traditional open approaches are associated with significant intraoperative blood loss and postoperative complications. Newer, minimally invasive techniques for interbody fusion and posterior spinal fixation have sought to decrease these complications. Lateral lumbar interbody fusion (LLIF) utilizes a lateral, retroperitoneal corridor to access the intervertebral disk spaces of the lumbar spine. This approach allows for placement of large diameter interbody cages and indirect decompression of neural elements without the associated risks of open anterior and posterior approaches. However, LLIF is not without its own unique complications secondary to violation of the psoas muscle during the approach, and anatomical variations in vascular and neural structures make the approach dangerous in some patients. Despite these challenges, LLIF remains a promising adjunct to posterior spinal fixation. This review will focus on the surgical technique, outcomes, and complication rates of LLIF in adult spinal deformity, as well as compare these parameters to alternative techniques including anterior lumbar interbody fusion, posterior lumbar interbody fusion, and stand-alone posterior spinal fixation.
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Introduction

Adult spinal deformity (ASD) comprises a complex spectrum of spinal diseases that present in adulthood including adult scoliosis, degenerative scoliosis, sagittal and coronal imbalance, and iatrogenic deformity, with or without spinal stenosis.[1] It is estimated that the overall prevalence of ASD in adults over the age of 60 is 6%.[2] With more than 11 million baby boomers in the United States achieving this age, the prevalence of this disease is steadily increasing.

The treatment of ASD is multifactorial and begins with a trial of nonoperative therapies. These include patient-initiated therapies such as physical therapy, stretching and aerobic conditioning, core strengthening, aqua therapy, walking, and cycling.[3] Oral medications such as nonsteroidal anti-inflammatory drugs can alleviate some symptoms as well. Other medications such as antidepressants and anticonvulsants could also be considered. Narcotic medications should only be reserved for acute exacerbations and given in short courses to avoid opioid dependence. Bracing serves a limited role in combination with exercise, as studies have demonstrated its inability to prevent curve progression in ASD.[4] Some patients also derive benefit from alternative treatments including acupuncture, chiropractic care, yoga, and pilates. Injection therapy is another alternative nonoperative option, especially for patients whose pain is primarily radicular in nature. While nonoperative therapy is the first-line treatment, many studies have demonstrated its inferiority when compared with surgical treatment, and diminished value with a significant cost only yielding minimal benefit.[5-7]

Once conservative treatments have been exhausted, the next logical step is consideration for surgical intervention. The main goals of surgery include decompression of the involved neural elements and re-establishment of coronal and sagittal plane balance. Indications include symptomatic low back pain and/or leg pain greater than 6 months in duration that has been treated with nonoperative efforts with

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worsening disability, documented progression of spinal deformity, presentation of neurologic symptoms, declining sagittal or coronal balance, and/or decompensation.[2,4] Contraindications include cardiopulmonary conditions or associated comorbidities, later stages of osteopenia, and any physical or mental condition that would impair patients from rehabilitation following the surgery. The choice of surgical approach is at the discretion of the treating surgeon, and options vary widely from anterior- or posterior-only surgeries, combined approaches, and additional techniques for correction including osteotomies and anterior column reconstruction with interbody grafting.

Lateral Lumbar Interbody Fusion

Introduction

The primary goal of any intelligently designed treatment for ASD is the restoration of balance in both the coronal plane and especially the sagittal plane, as this is directly correlated with patient outcomes.[8,9] Lateral lumbar interbody fusion (LLIF) has been a pivotal tool in the treatment of adjacent segment disease after prior lumbar fusion, affording large graft placement, disk height restoration, and indirect decompression while maintaining a safe and efficacious profile.[10] Recent attention has been given to the LLIF technique for addressing anterior spinal pathology.

Surgical Technique

The LLIF surgical technique was described by Ozgur et al in 2006,[11] which involves accessing the disk space via a lateral retroperitoneal corridor through the psoas muscle. It can be suitable for many conditions requiring interbody fusion from the disk spaces of L1/L2 to L4/L5, and especially in the treatment of coronal and sagittal plane deformity in ASD (Fig. 1).[12]

Preoperative Anatomical Considerations

Prior to the operation, the accessibility to each intended disk space needs to be scrutinized on plain radiographs and advanced magnetic resonance or computed tomography imaging. Importantly, LLIF is a lateral procedure that can be performed from the patient's right side or left side. Important factors to consider include the bony accessibility of the disk space and the location of the great vessels. For example, a levoscoliosis of the lumbar spine places the convexity to the patient's left, which makes it easier to access the disk space from the patient's left side. Additionally, the aorta typically sits further ventral on the left side as compared to the inferior vena cava on the right side, making the left side favorable for access to the lumbar spine disk spaces as well. However, a recent study by Mai et al[13] analyzing the location of critical anatomical structures on magnetic resonance imaging demonstrated an increased incidence in vascular variation

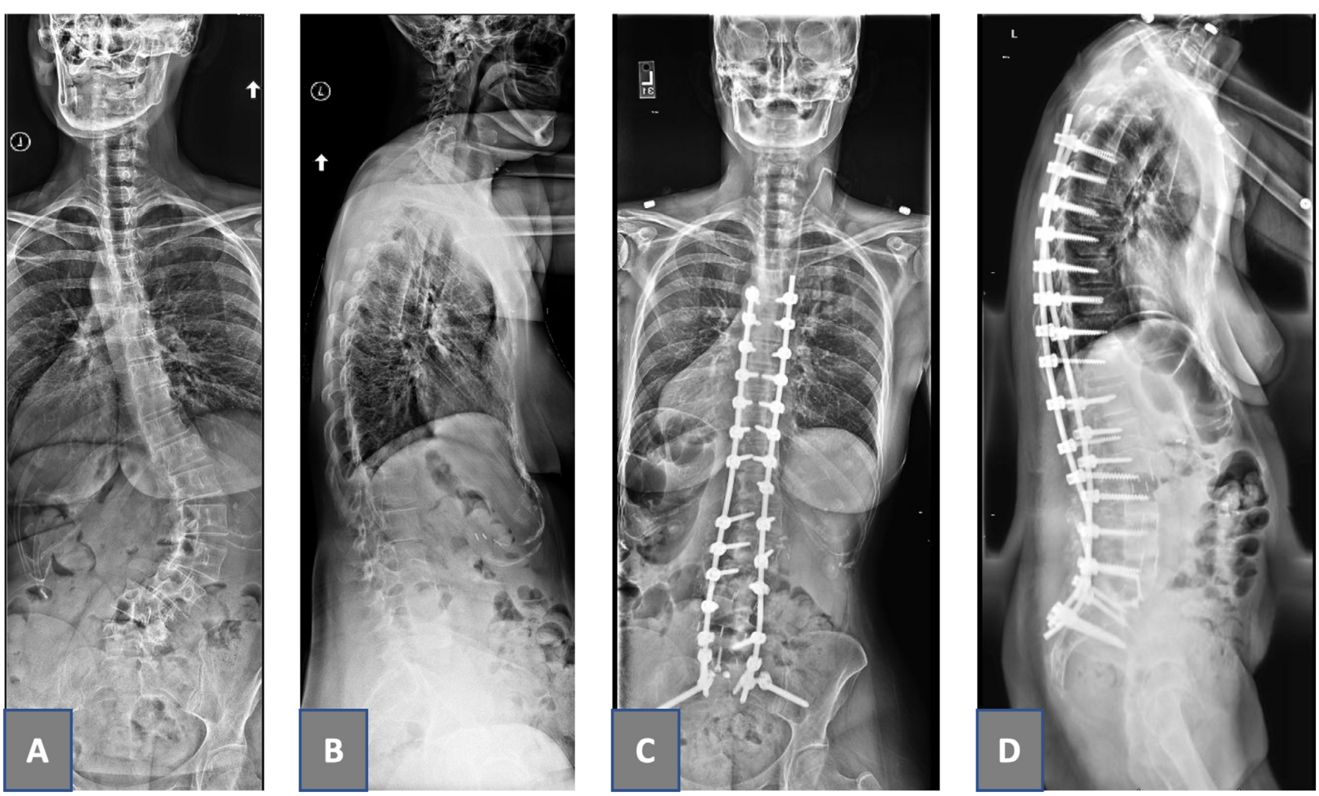

Figure 1 Case example, 47-year-old female with 5 years of back and radicular leg pain in the context of prior L4/5 microdiskectomy. She was treated with L3/4 and L4/5 LLIF, L5/S1 ALIF, T5-pelvis posterior spinal fusion. Coronal cobb angle preoperatively was 60° and lumbar lordosis 14° (A, B). These were corrected to 21° and 37° postoperatively, respectively (C, D).

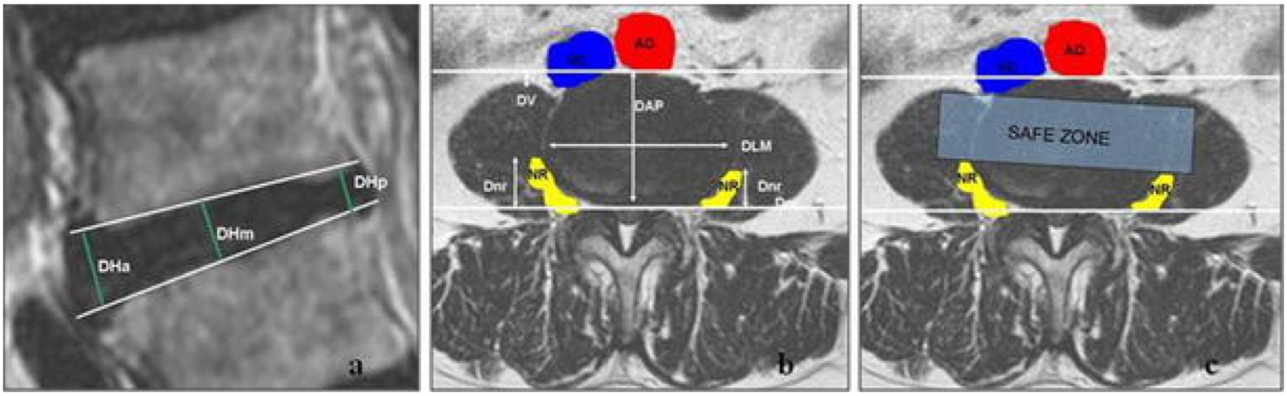

Figure 2 Axial MRI scan demonstrating the safe working zone for the lumbar lateral interbody fusion procedure between the exiting nerve roots dorsally and retroperitoneal vessels ventrally. Reprinted with permission from Guérin P et al.[14] MRI, magnetic resonance imaging.

in scoliotic patients, with 94.2% of the variants occurring on the convex side of the curve. This must be considered when approaching a scoliotic spine from the convex side. The last anatomical consideration is the location of the iliac crest in relation to the lumbar spine. In most people, the crest is at the level of the L4/L5 disk space. When positioned on the table, the patient is laterally flexed, effectively moving the iliac crest more caudal in relation to the lumbar spine on the side to be accessed. However, in some patients, accessing the L4/L5 or L5/S1 disk space is still difficult. Additionally, the lung and pleural space limit the rostral extent of the approach, typically leaving L1/L2 as the most rostral feasible disk space to be accessed with this technique.

Intraoperative Anatomical Considerations

The LLIF exploits an interval to the lumbar disk space that is retroperitoneal and approaches through the psoas muscle (transpsoas). Within the psoas muscle traverse the lumbosacral plexus, genitofemoral nerve, and lateral femoral cutaneous nerve. In general, the location of the plexus and these nerves moves from dorsal to ventral as one moves caudally. Because of the proximity of these nervous structures, intraoperative neuromonitoring is utilized and requires the use of anesthesia to allow for muscle twitches. Guérin et al[14] conducted a study reviewing 78 lumbar spine magnetic resonance imaging scans over a total of 304 lumbar vertebral levels to determine the safe working zone for the LLIF procedure. They identified the safe working zone in the sagittal plane to be ventral to the

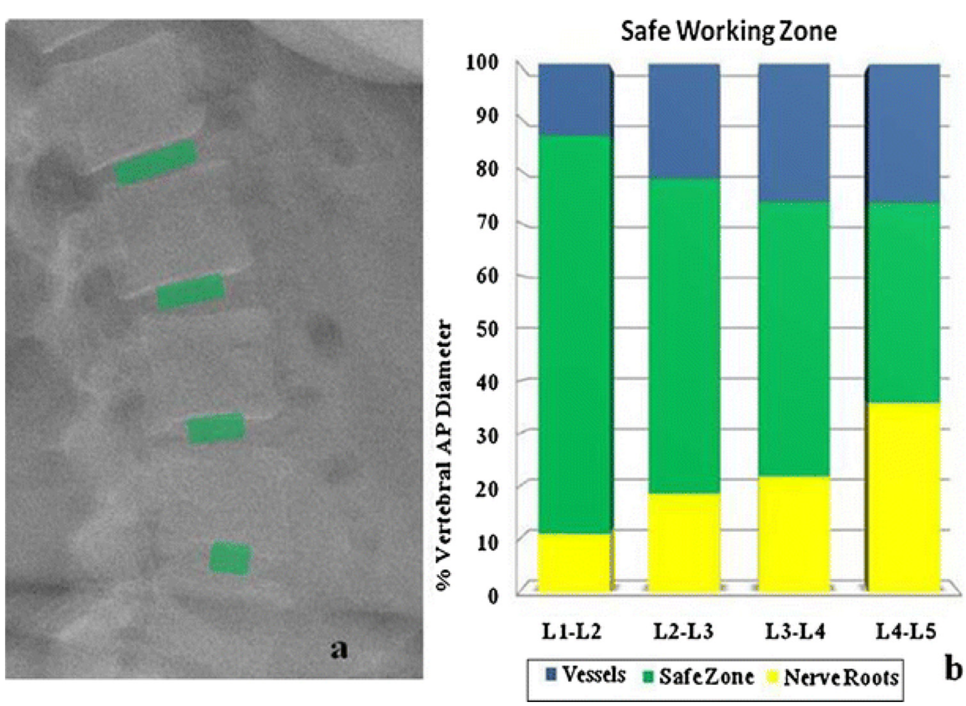

Figure 3 (A) Schematic representation of the safe working zones for the lumbar lateral interbody fusion procedure at L1-L2, L2-L3, L3-L4, L4-L5 levels (in green). (B) Overlap of the vertebral body with the nerve root and retroperitoneal vessels. Reprinted with permission from Guérin P et al.[14] (Color version of figure is available online.)

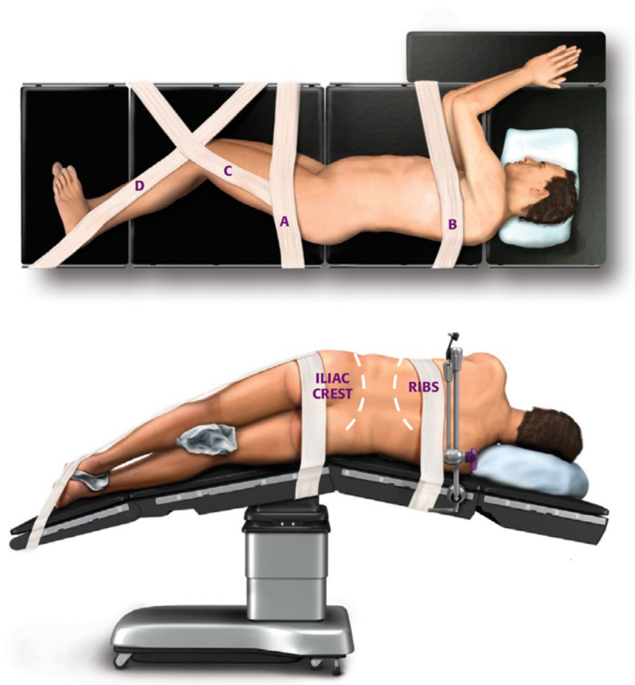

Figure 4 Patient positioning for LLIF procedure. The greater trochanter is slightly inferior to the table break. The tape is placed to secure the patient (A) just below the iliac crest, (B) over the thoracic region, (C) from the greater trochanter to the knee, and then secured to the table with padding placed between knees, and finally (D) from the table to the knee, past the ankle, and then secured to the table. Reprinted with permission from Pimenta L.[30]

exiting nerve roots and dorsal to the retroperitoneal vessels (Fig. 2). As one progresses from the L1/2 interspace caudally, the safe working zone becomes narrower, as the lumbosacral plexus nerves migrate ventrally (Fig. 3).

Patient Positioning

The patient is positioned laterally, either left or right side up depending on surgeon preference, the location of the retroperitoneal vessels on preoperative advanced imaging, and orientation of the coronal plane deformity (if present). A bed that is able to flex is paramount, as this allows the side to be accessed to become convex and enables easier access. The hips are flexed about 30° to take tension off the iliopsoas muscle, and knees are flexed about 30° to compensate for the hip flexion and keep the feet in a centered position on the bed. Once the patient is positioned appropriately, tape is used to maintain the lateral flexion of the trunk, and secure the patient's legs and chest on the table (Fig. 4). The bed is placed in reverse Trendelenburg at the base to allow the intended disk space to be perpendicular to the floor. A fluoroscopic C-arm should be able to freely image the intended disk spaces, and insuring perfect anteroposterior and lateral images of the intended disk spaces prior to draping the patient is helpful (Fig. 5). Additionally, when a perfect lateral image is obtained, a metal marking tool can be used to mark on the patient's skin the anterior and posterior edges of the disk space to guide the surgical incision (Fig. 6).

Surgical Approach

In general, a single- or dual-incision technique can be utilized. In both, a small transverse lateral incision is performed after localizing the disk space with fluoroscopic imaging. If a second incision is used, this is placed dorsal to the first incision made on the lateral edge of the erector spinae musculature. In the dual-incision technique, the more posterior incision is used for blunt dissection into the retroperitoneal space, allowing for sweeping of the retroperitoneum ventrally, prior to incising the lateral abdominal musculature through the more ventral skin incision (Fig. 7). Dissection is carried out sharply or with electrocautery through the layers of the abdominal wall musculature, then bluntly to sweep the retroperitoneum anterior to the working corridor. If a dual-incision technique is used, then a finger can guide and protect the instruments down to the level of the disk space, ensuring no sharp surfaces encounter the retroperitoneal structures (Fig. 8). If multiple levels are involved, a single longitudinal incision or multiple small transverse incisions paralleling each of the involved disk spaces can be used.

The first instrument passed to the level of the disk space is a guide wire that should be oriented at the junction of the middle and posterior one-third of the disk space and along the trajectory of the disk space, confirmed on lateral and anteroposterior fluoroscopic imaging, respectively (Fig. 9). Staying posterior to midline is important as subsequent insertion of shims to maintain retractor position and visualization can inadvertently release the anterior longitudinal ligament (ALL) if placed anterior to this point. After the guidewire is positioned, a successive series of dilators is placed over top, each connected to an EMG neuromonitoring system to help localize the motor nerves of the lumbosacral plexus. Finally, a retractor is placed over the largest dilator. Many surgeons prefer the "dock shallow" approach, whereby the dilators are placed superficial to the psoas muscle instead of through it, so that dissection can occur under direct visualization, reducing risk of neurologic injury—especially to the sensory nerves that are not detected by EMG neuromonitoring. The retractor is secured in its exact trajectory and depth by an attachment arm that connects to the bed side rail. The blades of the retractor depending on the system can open anteriorly or posteriorly. It is favorable to dock posteriorly and allow the blades to open ventrally, rostrally, and caudally—but not dorsally so as not to put traction on the lumbar plexus nerves.

Annulotomy and Disk Space Preparation

After retractor placement, the lateral annulus fibrosus is the first structure of the disk space encountered. Prior to beginning any surgical efforts at this point, a handheld neuromonitoring probe should be utilized to check for the surgical field's proximity to the exiting nerve roots and lumbosacral plexus within the psoas muscle. After insuring a safe working portal, the lateral annulus can be excised in rectangular fashion with a scalpel to expose the nucleus pulposus, which is removed with a combination of Kerrison and Pituitary rongeurs, curettes, and disk cutters (Fig. 10). Using a Cobb elevator, the annulus can be detached from the superior and inferior

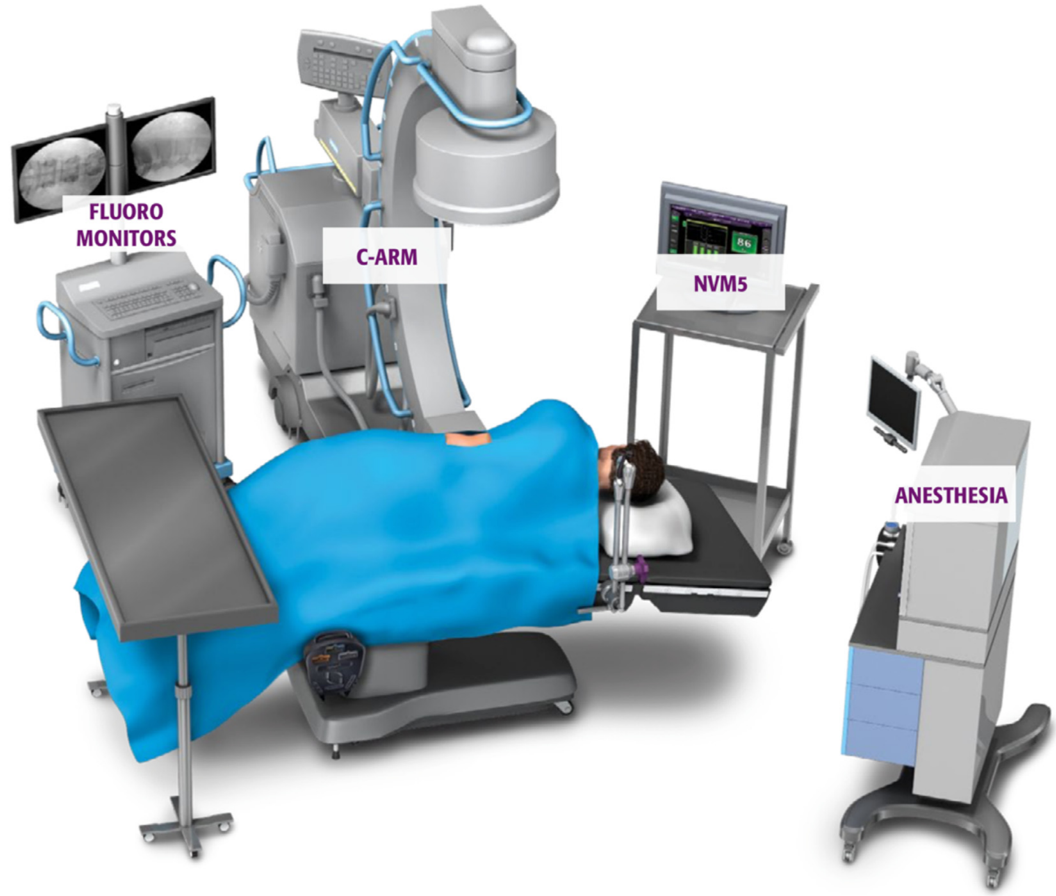

Figure 5 Operating room set-up for LLIF procedure. The surgeon stands on the posterior side of the patient, the fluoroscopic C-arm should be able to come in directly at the level to be accessed, with the monitor and nerve monitoring system (NVM5) close by. Reprinted with permission from Pimenta L.[30] LLIF, lateral lumbar interbody fusion.

endplates on the contralateral side, this is best done under anteroposterior fluoroscopy to insure the instrument is appropriately located and does not plunge too far past the endplate.

The endplates are prepared using a combination of curettes, pull shavers, rotary shavers, endplate scrapers, and rasps at the surgeon's discretion. The goal is to remove the entire disk and the cartilaginous endplate but not to violate the subchondral bone as this serves as the rigid platform on which the spacer will allow for disk space opening. If the subchondral bone is violated, the spacer cannot distract the disk space as effectively, and subsidence into the cancellous vertebral body is more likely.

Trialing and Sizing

Once the diskectomy and endplate preparation is complete, the interbody cage spacer is sized by placing sequentially sized dilators into the space, feeling the tension as the disk space distracts, and checking fluoroscopic imaging as needed (Fig. 11). The cage should be of appropriate width (in the coronal plane) to span both lateral rims of the endplates to allow for the best coronal plane correction and reduce the potential for cage collapse through the endplate. The depth of the cage (in the sagittal plane) should be sized to match the amount of dissection that was possible. Deeper cages offer a larger footprint, which is biomechanically favorable, however, it requires more dissection to fit the cage, which may or may not be possible. The height of the cage is determined by the tension on the distracted disk space while sizing with sequential dilator trials. Cage spacers can come with built-in lordosis alignment as well.

ALL Release (Anterior Column Realignment)

After the trials have identified a suitably sized cage spacer, the ALL can be released. This is sometimes called anterior column realignment and allows for additional induction of lordosis at the involved level. This involves careful dissection anterior to the ALL and placement of a retractor to protect the retroperitoneal vessels and separate them ventrally from the ALL. Leaving a trial in the disk space allows for tensioning of the ALL which makes it easier to release. The release is performed under tension with appropriate retraction allowing for direct visualization of the ligament.

Graft Preparation and Delivery

Most cages available are made of either polyetheretherketone or porous titanium. The cage has space available for packing bone graft material. The graft is impacted into place by itself or by using graft sliders to prevent endplate violation in the process.

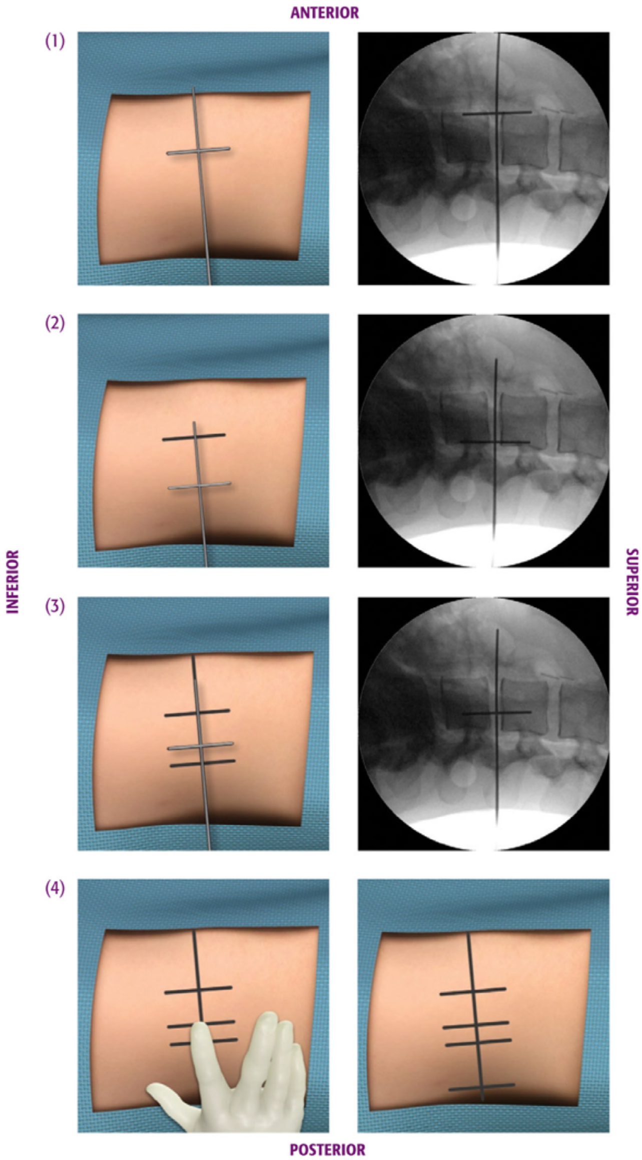

Figure 6 Incisions are easily marked using a targeting instrument and fluoroscopic imaging. The instrument is used to mark (1) the anterior border of the vertebral bodies, (2) the posterior border of the vertebral bodies, (3) the posterior third of the disk space, and (4) a transverse mark in line with the disk space. If 2 incisions are to be used, a second mark on the skin posterior to the first along the same line, just lateral to the erector spinae muscles is made. Reprinted with permission from Pimenta L.[30]

The final graft is checked on anteroposterior and lateral fluoroscopic imaging to confirm optimal placement (Fig. 12). Many cages allow for supplemental plate fixation to secure the graft to the adjacent vertebral bodies. These can be beneficial in the case of a concomitant anterior column realignment and when placing hyperlordotic cages to ensure the graft maintains a static position.

Closure

Hemostasis is achieved prior to retractor removal. The blades of the retractor are partially closed and the retractor is removed slowly, checking for hemostasis along the walls and confirming no retroperitoneal contents are caught in the

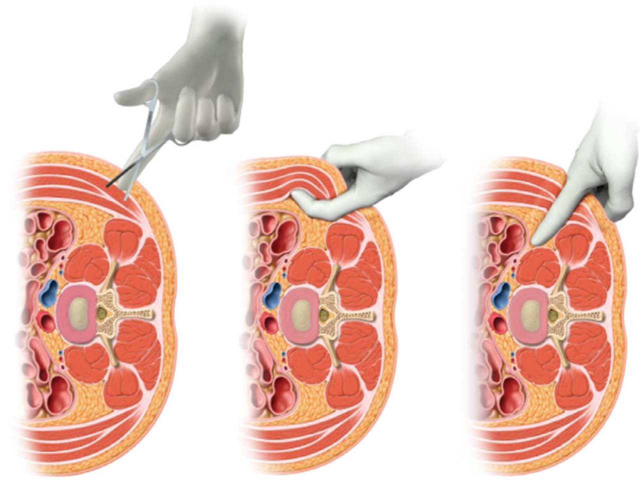

Figure 7 If 2 incisions are used, the posterior incision allows for dissection through the layers of the abdominal wall musculature into the retroperitoneal space. Once inside the retroperitoneal space, finger dissection is used to create space and release the peritoneum ventrally. After this, the psoas muscle can be palpated on the ventral surface of the transverse process. Reprinted with permission from Pimenta L.[30]

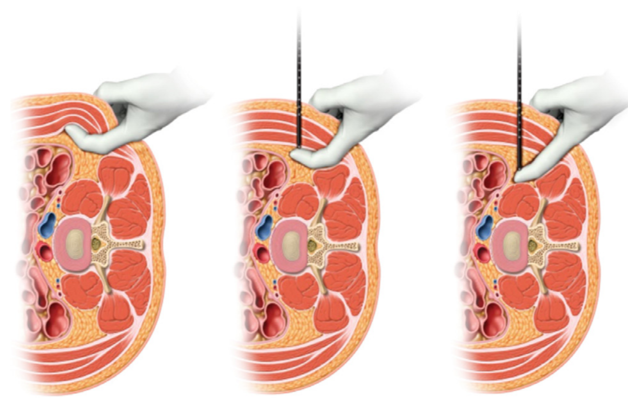

Figure 8 Through the ventral incision the same dissection through the layers of the abdominal wall musculature is carried out, and the initial dilator can be guided down to the psoas muscle. Reprinted with permission from Pimenta L.[30]

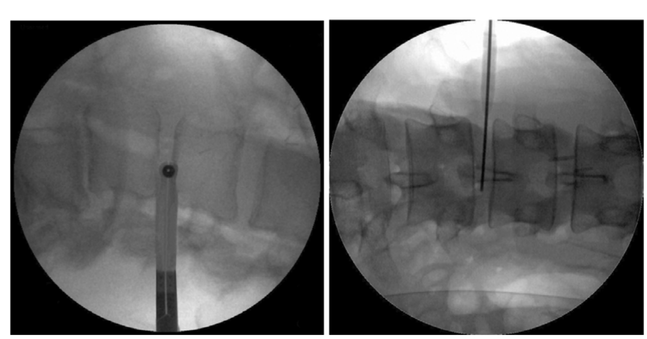

Figure 9 The docked position on the psoas is checked first on lateral fluoroscopy. After nerve monitoring confirms this is a safe position, it is confirmed to follow the trajectory of the disk space on anteroposterior fluoroscopy as well, after which a Kirschner wire can be introduced into the disk space to secure the position of the dilator. Reprinted with permission from Pimenta L.[30]

Figure 10 Once the disk is safely accessed, the lateral annulus fibrosus can be excised in rectangular fashion and disk space preparation instruments are used to perform a thorough diskectomy, contralateral annulus release, and endplate preparation. Reprinted with permission from Pimenta L.[30]

removal. A layered closure of the abdominal wall is preferable to prevent hernia. The skin is in a relatively tension-free area, which allows for a subcuticular skin closure with skin glue at the discretion of the surgeon.

LLIF Technique Pearls[10]

- Always start with preoperative imaging and identify psoas, nerves, and vessels
- Patient positioning is critical
- Avoid over-breaking the table and causing an L4 nerve traction injury
- Rotate the table and not the C-arm to obtain a true lateral and anteroposterior image
- Perform a single passage through the psoas, no wandering in the sagittal plane
- Utilize directional neuromonitoring
- Minimize retractor opening and retraction time
- Do not oversize the graft, this can lead to subsidence
- Backing up the interbody with supplemental posterior fixation is recommended

Benefits Over Other Approaches to Interbody Fusion

The LLIF has many advantages over traditional anterior lumbar interbody fusion. It does not require a general surgeon for access, the need to retract or violate the peritoneum is eliminated, and the approach avoids mobilization of the retroperitoneal vessels, thus avoiding the related risk of sexual dysfunction.[15,16] It also offers safer access to the retroperitoneal space and disk space in patients who have had prior abdominal surgery. It also provides the ability to release, reconstruct, and fuse the anterior column, and indirectly decompress the neural elements by disk distraction and correction of spinal alignment.[8,17]

The LLIF also has advantages over posterior interbody fusion techniques such as the posterior lumbar interbody fusion and transforaminal lumbar interbody fusion. In comparison to these, the LLIF allows a more complete diskectomy, annulectomy, osteotomy, and insertion of a larger interbody device. The placement of an interbody device able to restore height to the disk space, which enables in some cases enough foraminal decompression to relieve symptoms

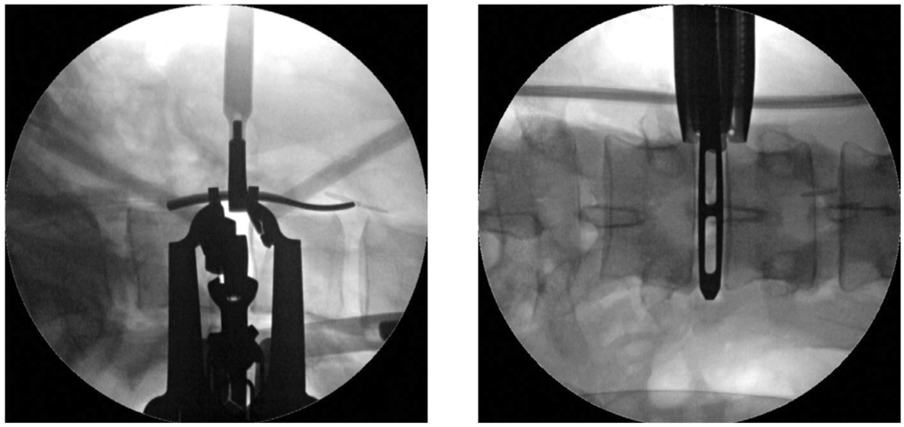

Figure 11 Sequentially larger trial dilators are placed into the disk space to evaluate for final implant sizing, which can be checked for fit on fluoroscopic imaging. Reprinted with permission from Pimenta L.[30]

without the need for laminectomy. It also results in limited posterior paraspinal muscle dissection and helps to avoid epidural scar dissection during revision procedures.[18,19]

In general, newer technologies and methods in minimally invasive spine surgery such as LLIF have proved advantageous for both patients and surgeons. Shorter surgery times, decreased hospital stays, decreased tissue trauma and blood loss, decreased postoperative pain, and a shorter return to daily life are all reported advantages associated with minimally invasive spine surgery.[20-22] Furthermore, LLIF has been combined with posterior spinal fusion (PSF) to create a successful strategy for the staged correction of spinal deformity.[8,22] With the growing prevalence of ASD and surgical treatments thereto, it is important to understand the potential benefits and risks offered by the LLIF as an adjunctive treatment.

LLIF as an Adjunct to Posterior Spinal Fusion

Recent studies have demonstrated that when LLIF is combined with PSF, patients report less back pain, less disability, and better SRS-22 outcome scores; and patients have significant improvement in mean sagittal vertebral axis and lumbar lordosis.[23] Strom et al[24] demonstrated superior coronal plane correction and greater restoration of lumbar lordosis in patients

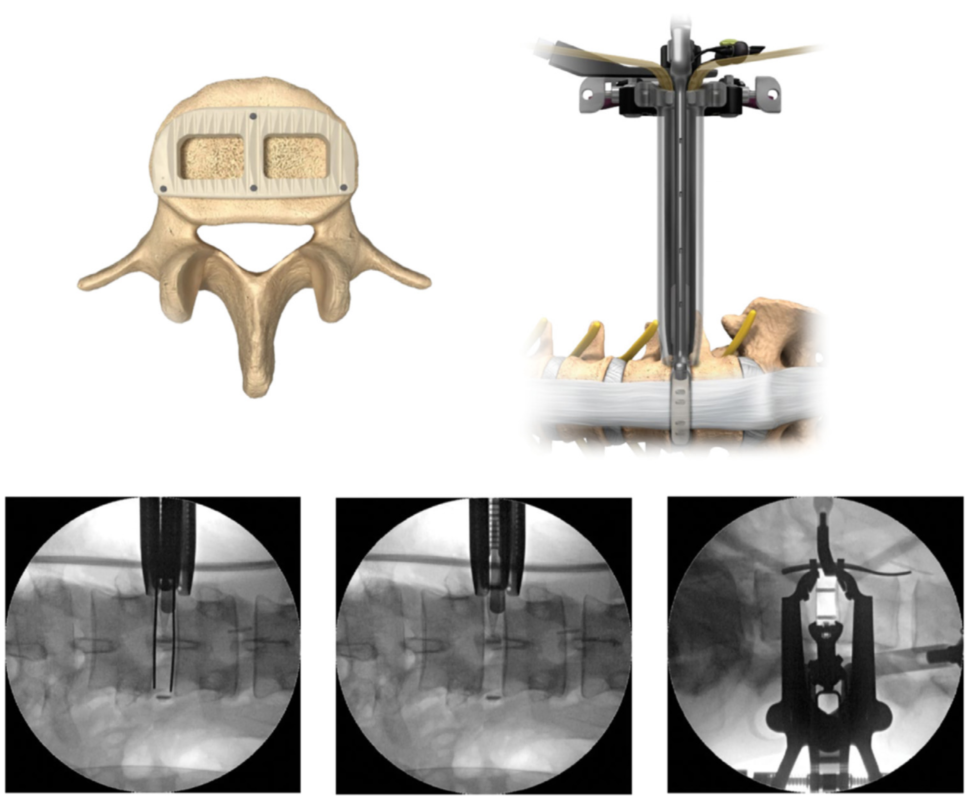

Figure 12 Final implant insertion is performed under anteroposterior fluoroscopic imaging and can be performed with or without protective slides to shoehorn the graft into place. The final position is checked on lateral imaging as well to confirm optimal placement in the sagittal plane. Reprinted with permission from Pimenta L.[30]

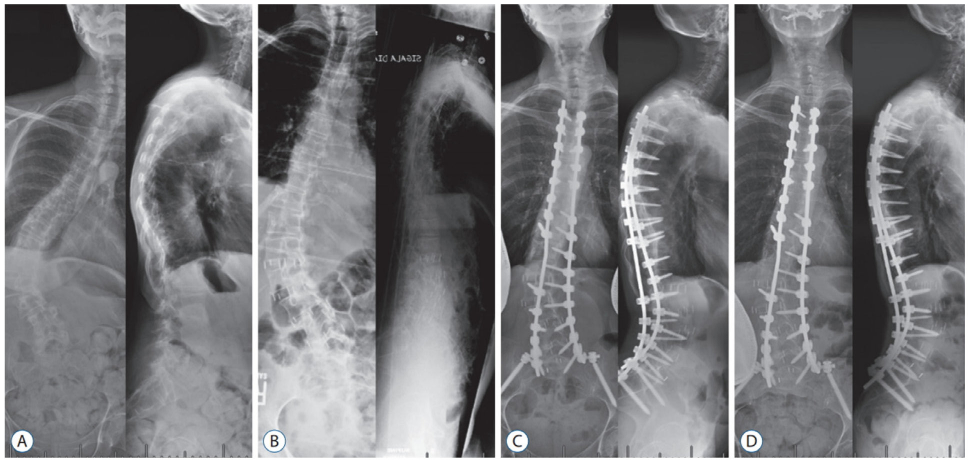

Figure 13 Demonstrated here (A) a 60-year-old female with preoperative coronal Cobb angle of 69° and lumbar lordosis of 46° were corrected to (B) 47° and 60° after lateral interbody fusion and to (C) 26° and 58° after posterior spinal fusion. The angles measured (D) 27° and 54°, respectively at 2 years postoperatively. Reprinted with permission from Choi SW et al.[8]

who underwent combined LLIF and open-PSF when compared to patients who underwent open-PSF alone. In this study, patients in the combined group also reported significantly more improvement in back pain and disability.[24] Park et al[25] also demonstrated significantly better restoration of lumbar lordosis in the combined group in their study. The authors found that in the combined group, postoperative canal area and foraminal height were significantly higher than preoperative values, providing evidence that LLIF is effective in achieving indirect decompression of neural elements.

Choi et al[8] examined the isolated effect of LLIF in the staged management of ASD. They treated 40 patients with ASD in 2 stages. The first stage involved performing LLIF on the indicated lumbar levels using a lordotic interbody cage packed with allogeneic bone graft substitute. The cages ranged from 45 to 60 mm in length, 8 to 12 mm in height, 18 to 22 mm in width, and lordosis angle between 10° and 30°. This first stage was followed by an interstage of 1-6 days wherein the patient underwent standing long cassette 36 anterior-posterior and lateral radiographs and were adequately resuscitated for the second stage. The second stage included posterior decompressive laminectomies, placement of pedicle screws, laminar hooks, and iliac screws. When comparing preoperative, interstage, and final follow-up imaging, overall correction, and correction attributable to LLIF alone could be gleaned. On average, they were able to correct lumbar lordosis from 36.4° to 56.1° and 71.3% was attributable to the LLIF. The thoracic coronal Cobb angle was corrected from 20.8° to 9.3° and 41.4% was attributable to the LLIF. The lumbar coronal Cobb angle was corrected from 19.2° to 15.7° and 55.9% was attributable to the LLIF. The sagittal vertical axis was corrected from 61.7 to 42.0 mm and 18.0% was attributable to the LLIF (Fig. 13). The authors concluded that LLIF combined with staged PSF provides excellent radiographic outcomes in the treatment of ASD.

Phillips et al[17] conducted a multicenter prospective cohort study enrolling 107 patients with ASD and treating with LLIF in all cases. The LLIF alone was used in 18% of cases, anterolateral fixation supplemented in 7% of cases, and posterior fixation supplemented in 76% of cases. At 24-month follow-up, they found an overall patient satisfaction rate of 86% (patients stating they would repeat the surgery), in addition to significantly improved metrics with regard to Oswestry Disability Index, Visual Analog Scale for pain in the back and leg, and Short-Form 36 patient-reported outcome measures. The average coronal Cobb angle was corrected from 20.9° to 13.5° immediately postoperatively, settling to 15.2° at final follow-up. Degree of Cobb angle correction did not correlate with clinical outcomes. Average lordosis in patients with hypolordosis (L1-S1 lordosis <40° preoperatively) corrected from 27.7° to 37.6° immediately postoperatively, settling to 33.6° at final follow-up. Mean disk height increased from 5.2 mm preoperatively to 8.7 mm immediately postoperatively and settled to 7.5 mm at final follow-up. Fusion rates at time of final follow-up were 58% solid fusion, 39% partial fusion, and 3% no consolidation. Eight percent of patients had at least 1 level described as a pseudoarthrosis. The authors noted that the extent of bony consolidation was dependent on fixation method, with the greatest percentage of solid bridging bone in LLIF patients supplemented with bilateral pedicle screw instrumentation. The authors concluded that LLIF results in favorable clinical and radiographical results in the treatment of ASD, with supplemental posterior fixation offering the greatest correction and fusion profile.

McAfee et al[22] reviewed a consecutive series of 25 patients who underwent LLIF in conjunction with posterior osteotomies and pedicle screw instrumentation. At a mean follow-up of 24 months, 85% of patients demonstrated evidence of solid arthrodesis and no subsidence based on computed tomography and flexion/extension radiographs. LLIF alone was found to anatomically reduce lateral listhesis and anterior spondylolisthetic subluxations. The authors' concluded that LLIF combined with posterior osteotomies and instrumentation is indicated in ASD patients, especially those with truncal decompensation evidenced by imbalance of 2 cm or more in the coronal or sagittal plane.

Berjano and Lamartina[26] reviewed the literature on the use of LLIF in ASD and found that LLIF with posterior percutaneous pedicle screw instrumentation provides 40%-75% correction of coronal curves with only a modest increase in lordosis. LLIF alone in their review could provide less correction than if combined with the posterior percutaneous procedure. They concluded that LLIF is a promising minimally invasive option for ASD that may have a lower complication rate when compared to open circumferential surgery in historical series.

Complications

There are many approaches to lumbar interbody fusion during deformity surgery, each with its own unique set of dangers arising from the pertinent anatomy. Anterior approach complications include damage to the abdominal organs (<1%), vascular injury (1.3%-15.6%), disruption of the sympathetic plexus (1.7%-13.3%), and postoperative ileus (0.6%-5.6%).[27] Posterior approaches avoid the aforementioned risks but can afford soft tissue devitalization, nerve root injuries (9%-16%), postoperative radiculitis (6.7%-16.4%), and incidental durotomies (5.4%-10%).[27] The lateral transpsoas approach to the anterior lumbar spine eliminates the need for retraction of the great vessels and has the potential for shorter operative times compared with the traditional open approaches; however, it is not without its own unique set of complications.

The pertinent potentially dangerous anatomical structures germane to the LLIF are the lumbar nerve roots as they exit the neural foramina and travel through the psoas muscle to form the lumbosacral plexus. Injury to these structures can lead to pain, neuropraxia, and weakness. There is wide variation in the incidence of these injuries, ranging from 6.2% to 52%. Sofianos et al[27] examined 45 patients undergoing 71 LLIF procedures and found an overall complication rate of 40%. The most common complications included iliopsoas weakness (22.2%), anterior thigh numbness (17.8%), quadriceps weakness (6.7%), and radiculopathy (6.7%). There did not seem to be an increase in complications if 1 or multiple levels were being performed in the same surgery. The majority of complications in this study occurred at the L3/4 level, followed by the L4/5 level; although the L4/5 level is traditionally the more common level to encounter neurologic complications due to the more anterior position of the lumbosacral plexus within the psoas muscle. Of the patients developing iliopsoas weakness, one-half had resolution at an average of 5 months postoperatively. Of the patients developing anterior thigh numbness, 88% persisted at an average of 9 months postoperatively. Of the patients developing quadriceps weakness, two-thirds persisted at an average of 21 months postoperatively. Of the patients developing radiculitis, one-third resolved with a selective nerve root injection, one-third resolved without any intervention, and one-third persisted at 11 months postoperatively. Additionally, they had 1 patient who developed urinary retention, 1 that developed an incisional hernia, and 1 that developed a postoperative ileus. Unfortunately, there was 1 patient who developed a pulmonary embolism on postoperative day 15 and subsequently passed away.

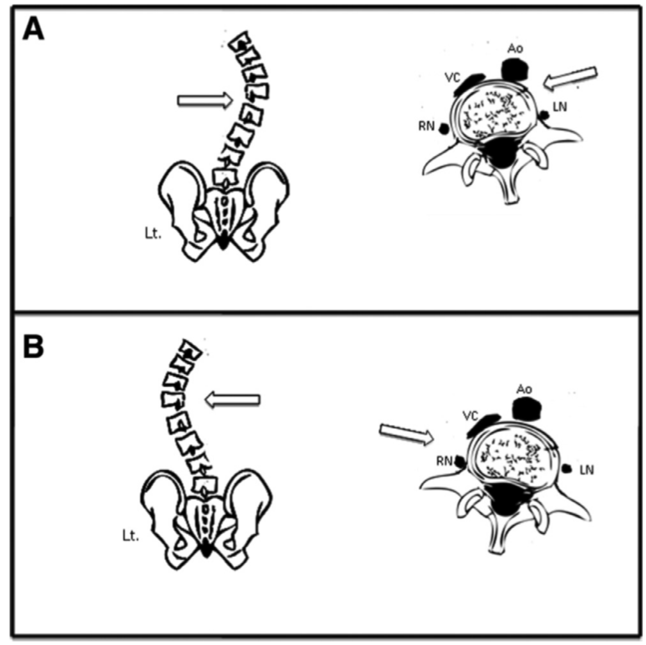

Figure 14 (A) Dextroscoliosis of vertebrae results in relative anterior position of the right nerve root and posterior position of the left vessel and nerve root. (B) Levoscoliosis results in relative anterior position of the left nerve root and relative posterior position of the right vessel and nerve root (arrows pointing at the concave side of the deformity). Reprinted with permission from Regev GJ et al.[28]

Other less common complications not seen in the above study include vertebral fracture, endplate fracture, iatrogenic herniated nucleus pulposus, graft subsidence, hardware failures, loss of fixation, retroperitoneal hemorrhage, hematoma, wound infection, durotomy, pneumothorax, and peritoneum perforation.

Of special interest in the use of LLIF for spinal deformity cases, vertebral rotation that is often present can alter the relative position of the retroperitoneal vessels in relation to the typical safe working corridor and make access in these situations much more difficult. Regev et al[28] performed a morphometric analysis of the safe corridor for LLIF in normal and deformed spines. In deformed spines they found that right vessels overlap on the vertebral body in levoscoliosis reached 43.9% compared to 12.2% in normal spines, and in dextroscoliosis the left vessels overlap on the vertebral body was 19.8% compared with 1.2% (Fig. 14). In our opinion, rotation of over 45° may limit the ability to place a cage safely given the relative translation of the retroperitoneal vessels; as well as impaired ability to obtain adequate fluoroscopic imaging with the LLIF set-up.

Additionally, the L4-5 level can be challenging in certain cases when the psoas muscle is in a more ventral position than normal, bringing the lumbosacral plexus into a prohibitive position in relation to the LLIF desired access to the L4-5 disk space. This phenomenon has been coined the “rising psoas sign” by Voyadzis et al, and identifying a rising psoas muscle at L4-5 on axial imaging preoperatively may preclude the LLIF approach from being performed (Figs. 15 and 16).[29]

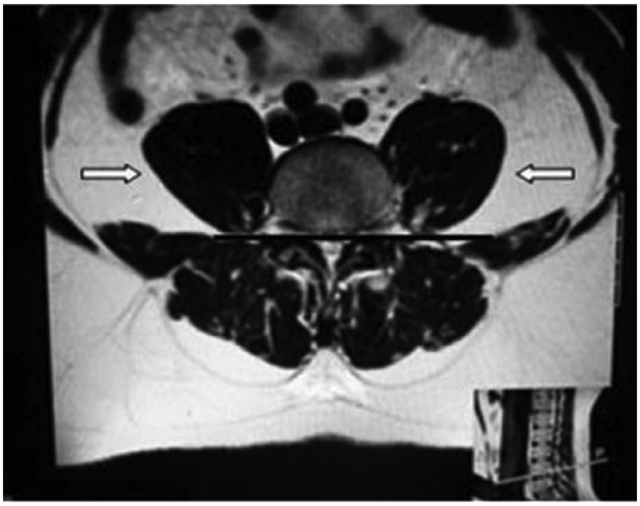

Figure 15 Axial T2-weighted MR images demonstrating typical psoas anatomy at L4-5 where the psoas muscle lies lateral to the vertebra (arrows and black line). Reprinted with permission from Voyadzis J-M et al.[29]

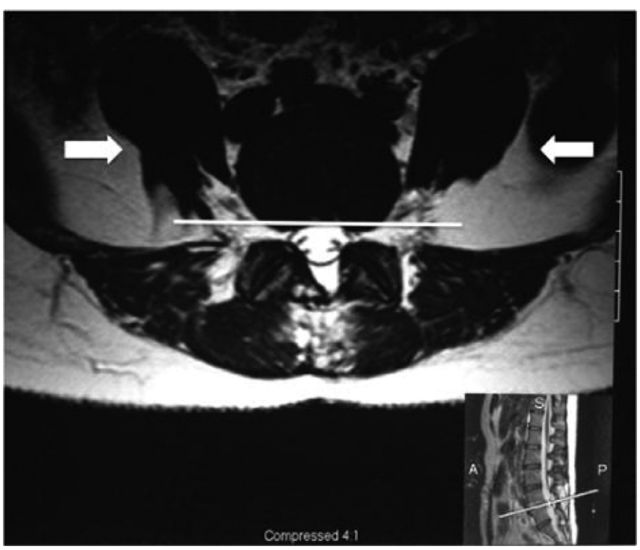

Figure 16 Axial T2-weighted MR image obtained in a 39-year-old female patient who underwent a lateral interbody fusion at L4-5 for degenerative disk disease. The psoas muscles are located ventral and lateral to the L4-5 disk space. She had persistent paresthesias and leg weakness for 6 months after surgery. Reprinted with permission from Voyadzis J-M et al.[29]

Conclusion

ASD remains a challenging problem to treat due to its surgical morbidity. Newer minimally invasive approaches such as the LLIF have been refined to allow for less iatrogenic morbidity, however, it is not without its own unique set of anatomical considerations and potential for serious complications. Nevertheless, lateral lumbar interbody fusion has proven a useful adjunct to traditional posterior spinal fusion in the treatment of adult spinal deformity.

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