Lateral Lumbar Interbody Fusion

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Abstract

Lateral lumber interbody fusion is an important technique in the continually growing field of minimally invasive spine surgery. While it had previously been utilized in the early twentieth century for the treatment of traumatic injuries and Pott's disease, the current revolution of minimally invasive surgery has seen a recurrence of this approach and expansion of its clinical applications. Though this approach was largely abandoned in the late twentieth century for anterior and posterior approaches due to a high morbidity, a combination of improved technology and understanding of lumbar plexus anatomy has allowed for

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its resurgence. Clinical applications of the retroperitoneal trans-psoas and pre-psoas approaches are continually expanding and frequently include scoliosis, neoplasms, traumatic injuries, and a variety of degenerative disorders. Here we describe the clinical utility of this approach, review the pertinent clinical anatomy, and describe the procedure in detail.

Keywords

Lateral lumbar interbody fusion · Trans-psoas · Pre-psoas · LLIF · OLIF · Minimally invasive spine surgery

Introduction

Interbody fusion in the lumbar spine is an established treatment for a wide variety of spinal disorders ranging from trauma, infection, degenerative disease, deformity correction, and neoplasms. The use of interbody fusion provides additional biomechanical advantages because of the ability to place a large interbody graft that provides support to the anterior and middle columns of the vertebral segment. Additionally, the ability to extend the graft across the thicker bone of the apophyseal ring of the vertebral body limits subsidence or fracture. Restoration of interbody height by interbody fusion allows for indirect decompression of the neural elements. The goals of treatment and surgical approaches to the spine vary based upon the spinal pathology. The options are circumferential, including the posterior lumbar interbody fusion (PLIF), transforaminal lumbar interbody fusion (TLIF), lateral lumbar interbody fusion (LLIF) either pre-psoas or trans-psoas, and anterior lumbar interbody fusion (ALIF). Of these techniques, the lateral interbody approach is growing in popularity due to avoidance of the vasculature anteriorly and the thecal sac posteriorly. Additionally, there is minimal disruption of the existing ligamentous structures and surrounding musculature. The LLIF has multiple trade names depending on the company. The trans-psoas approach is called the direct lumbar interbody fusions (DLIF) or extreme lateral interbody fusion (XLIF). The pre-psoas approach is called the oblique interbody fusions (OLIF).

Compared to traditional anterior and posterior approaches to the lumbar spine, the minimally invasive lateral interbody fusion is a relatively new approach as it relates to common practice. But it is important to note that variations of this approach have been described historically. Although lateral approach to the lumbar spine was originally described and utilized in the treatment of Pott's disease in the early twentieth century by Drs. Menard and Capener, it remained infrequently used due to injury to the traversing lumbar plexus and nerve roots. Despite this neurologic morbidity, the approach became more commonplace in the treatment of Pott's disease through the twentieth century. With the emergence of the minimally invasive revolution in the late twentieth century, this approach reemerged and expanded to include a wide variety of disease pathologies. This expansion is largely attributed to recent advances in minimally invasive technologies and a better understanding of the anatomic relationships of the exiting lumbar nerve roots that form the lumbar plexus. While the traditional lateral approach accessed the vertebral column using a trans-psoas corridor, Mayer in 1997 described an oblique retroperitoneal approach in which instrumentation is performed anterior to the psoas with the benefit of fewer neural injuries (Mayer 1997). Once these anatomic limitations were identified and techniques developed to limit nerve injury, lateral approaches to the lumbar spine have proven to be versatile tool in modern spine practice.

The lateral lumbar interbody fusion has demonstrated some distinct advantages compared with the anterior or posterior approaches to the lumbar spine. Compared with traditional approaches, there is minimal disruption of the posterior elements, which may provide some benefit in the stability of the construct and postoperative pain. Additionally, lateral approaches allow for a larger access to the disc space and increase the size of interbody graft compared to posterior approaches. Research has demonstrated decreased blood loss and operative time as compared with traditional approaches. One review evaluating extreme lateral lumbar interbody fusion (XLIF) demonstrated overall short operative times, 199 min, and relatively minimal blood loss of 155 ml (Youssef et al. 2010).

Compared to traditional ALIF approaches, lateral interbody fusion demonstrated similar degrees of foraminal height gain. However, there was less segmental lordosis correction than ALIF. In previous studies the amount of foraminal height following ALIF has demonstrated improvements in foraminal height of approximately 2.7 mm. Alimi et al. demonstrated similar foraminal height improvements, 2.5 mm on average, in their series of 145 patients who underwent interbody fusion from a lateral approach (Alimi et al. 2014). As compared to ALIF, however, segmental lordosis correction in lateral interbody fusion is generally less due to retention of the anterior longitudinal ligament. While specific degrees of improved lordosis vary, ALIF generally provides approximately 4.5° of lordosis, but only 2.5° following a lateral approach (Winder and Gambhir 2016).

Indications and Contraindications

The indications of the lateral lumbar interbody fusion are primarily to improve intervertebral height and to reduce deformity. Common indications are degenerative disease with loss of disc height and foraminal stenosis, spondylolisthesis, coronal imbalance, lateral vertebral subluxation, and revision of adjacent segment degeneration.

The contraindications of this approach are primarily related to anatomical considerations such as aberrant vascular anatomy, prior retroperitoneal approach, or prior abdominal infections or surgeries with associated adhesions in the retroperitoneal corridor. A high-riding iliac crest or low-lying rib is a relative contraindication.

Relevant Anatomy

The lateral lumbar approach traverses anatomy that is rarely encountered in traditional approaches. Given the narrow operative corridor, a detailed understanding of the relevant anatomy is crucial for safe, effective surgery. Traversing the retroperitoneal space involves significant risk to major vascular structures and vital organs. Evaluation of the preoperative imaging and understanding the location of these structures and their relationship to the disc space is a critical part of preoperative planning and intraoperative crisis management. Furthermore, if concern for major vessel injury arises preoperatively or intraoperatively, the surgeon should seek vascular surgery consultation.

When accessing the retroperitoneal space, care must be taken to first identify the external oblique fascia, external oblique, internal oblique, and transversus abdominal muscles at the beginning of the approach (Fig. 1). It is important to recognize the trajectory of the iliohypogastric and ilioinguinal nerve as they course through the psoas before innervating the internal and external oblique muscles. When unclear as to which muscular layer is being visualized, the surgeon should recognize the direction of the muscle fibers for reorientation. Once these muscular layers have been traversed, a layer of adipose tissue is identified in the retroperitoneal space. Deep to this, the peritoneum will be identified. Dissection is best performed bluntly with either finger dissection or use of cotton kittners. It is easier to dissect along the interior of the abdominal wall, palpate the iliac crest, and then identify the psoas than to try and dissect along the peritoneum. Further dissection leads to the lateral aspect of the psoas (Fig. 2). Care must be taken to expose the anterior psoas as it is easy to fall into a plane behind the psoas that leads to the spinal canal and foramen. The ureter typically will mobilize with the peritoneum and reflect anteriorly. However, if it is taking an unusual course, it can be identified by its visually identifying peristalsis with manipulation. Care should be taken to not overly compress or stretch the ureter. A keen awareness of the location of the great vessels anterior to the vertebral bodies is paramount. These can be palpated but care should be taken to avoid manipulation or retraction without adequate visualization. Segmental arteries will arise from the aorta in the midpoint, “valleys,” of the vertebral bodies. Occasionally, the iliolumbar vein or veins will be

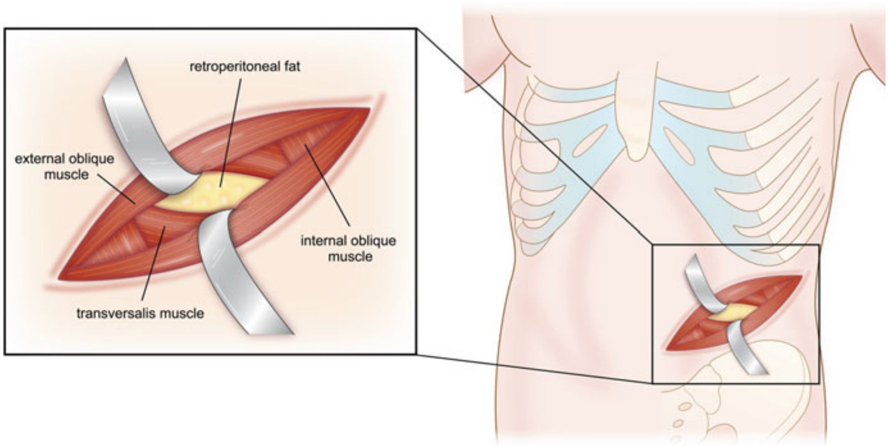

Fig. 1 This illustration shows the oblique incision, which is centered over the disc of interest and oriented along the fibers of the external oblique. Blunt dissection is performed through the external, internal, and transversalis abdominal muscles to reveal the retroperitoneal fat pad. (Reprinted with permission, University of Wisconsin © 2018. All Rights Reserved)

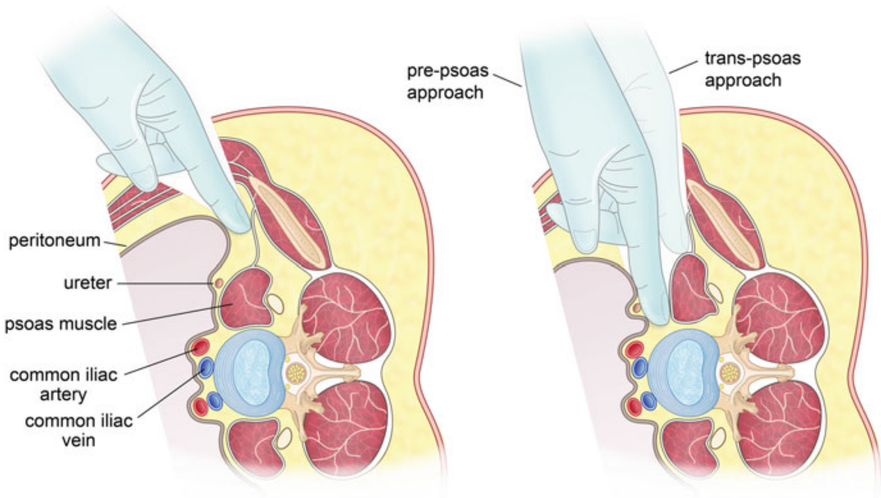

Fig. 2 Schematic demonstrating blunt dissection of the retroperitoneal fat pad from the transversalis fascia and anterior retraction of the aorta. The transverse process is first palpated before isolating the psoas muscle. If electing to perform a trans-psoas approach, instrumentation is then directed through the psoas under imaging guidance and neuromonitoring (triggered and free-running EMG). In the pre-psoas approach, the anterolateral portion of the vertebral body is identified (left) and the psoas is retracted posteriorly. Care should be taken to avoid dissection of the psoas medially, as this may irritate exiting nerve roots. (Reprinted with permission, University of Wisconsin © 2018. All Rights Reserved)

seen coursing from underneath the aorta usually at L4–L5 interval. This vein could be isolated and ligated to avoid avulsion of the vein from the inferior vena cava which can create a vascular injury that is very difficult to repair. During the course of dissection, if there is aberrant or overly large vascular anatomy, then strong consideration should be given to (1) obtaining vascular surgeon consultation, (2) aborting the procedure, and (3) operating via a posterior approach. Furthermore, a thorough review of preoperative imaging is important to understand the relation of adrenal glands, kidneys, ureters, and renal vasculature that may be encountered when utilizing this approach.

Lumbar Plexus

The lumbar plexus is deeply integrated into the psoas muscle and contains innervation from subcostal contributions from the T12 as well as the ventral rami of the first four lumbar nerve roots. The fourth lumbar nerve root additionally supplies contributions to the sacral plexus. The lumbar plexus is ultimately divided into two divisions named the anterior and posterior division. The posterior division provides innervation to the main motor component of the posterior leg via the femoral nerve with contributions from the L2 to L4, while the anterior division provides motor innervation via the obturator nerve. Sensory innervation is chiefly accomplished by the iliohypogastric, ilioinguinal, genitofemoral, lateral femoral cutaneous, and anterior femoral cutaneous nerves.

Understanding the course of the ilioinguinal and iliohypogastric nerve is vital to avoiding complications. Both nerves run posterior to the psoas major on its proximal lateral border of the vertebral bodies and then travel along the anterior border to the quadratus lumborum. After traveling anterior to quadratus lumborum, the ilioinguinal nerve pierces the lateral abdominal wall after traveling at the level of the iliac crest to supply sensory innervation to the external ring, the area over the pubic symphysis, and the lateral area of the scrotum or labia majora. Comparatively the iliohypogastric provides motor innervation to the abdominal internal oblique and transverse abdominis until it provides a terminal cutaneous branch supplies which the skin above the inguinal ligament.

The lateral cutaneous nerve consequently pierces the psoas directly through a lateral approach most frequently in the middle location of the psoas muscle. Given its location directly through the psoas muscle, this nerve is at risk during a lateral lumbar approach. Once it emerges from the psoas, it then courses across the iliacus muscle obliquely and continues to the anterior superior iliac spine. At this point it crosses under the inguinal ligament over the sartorius muscle into the thigh.

The femoral nerve is the longest and largest nerve of the entire lumbar plexus and supplies both sensory and motor innervation to the anterior compartment of the superior leg. Contributions from the lumbar plexus arise from the L2, L3, and L4 nerve roots. After arising distal to the nerves to the psoas muscles directly, it courses through the femoral triangle lateral to femoral artery.

Vascular Anatomy Considerations

When considering a lateral retroperitoneal approach, important consideration of the major vascular structures such as the inferior vena cava, abdominal aorta, and common iliac arteries and veins must be given. In order to limit the potential injury to vascular structures, a careful review of the preoperative imaging is vital. While risk to the great vessels is highest at the L4–L5 level due to their lateral migration, major vasculature injury could occur at any level. In addition to knowledge of the great vessels, care should be taken to identify and avoid avulsion of any of the segmental vessels or iliolumbar veins crossing into the disc space during removal of the annulus that could result in avulsion of the aorta or vena cava.

Preoperative Planning and Operative Window

In considering the operative corridor during interbody fusion, it is vital to understand what constitutes a safe and effective operative window. Avoiding injury to the traversing nerve roots and lumbar plexus and great vessels is paramount. It is also important to consider that surface anatomy: a high-riding iliac crest or low-riding ribs can make the approach more difficult. These surface limitations can be managed by removing rib or positioning the hip over a bump or table break. Care should be taken to not overextend the torso as this can cause thigh pain and weakness.

Trans-psoas

The trans-psoas approach avoids the great vessels but puts the lumbar plexus and peripheral nerves at greater risk of injury. The anatomy of the plexus cannot be well discerned on preoperative imaging. So, determination of an operative window is made intraoperatively via a combination of general knowledge of the lumbar plexus anatomy, visual and fluoroscopic inspection, and the use of neuromonitoring (triggered and free-running EMG).

Despite attempts to simplify the anatomical association of the lumbar plexus and the psoas muscle, the authors have demonstrated enormous variability. The plexus generally tends to migrate anteriorly as the psoas muscle enters the pelvis. Due to this relationship, the plexus is often at highest risk of injury at the L4–L5 disc space. A key development occurred in 2010 when Uribe et al. published a cadaveric study in which the zones of safest psoas disruption were identified (Uribe et al. 2010a). In this system four quartiles along the sagittal axis of the vertebral body were defined at each vertebral level. At the L1 and L2 disc space, the middle of this quartile was shown to have the lowest risk for injury to the nerve roots or lumbar plexus; however, at lower levels, the safest location migrates slightly anteriorly until the L4–L5 disc space. At the L4–L5 disc space, the safest location was the midpoint of the vertebral body. Additionally, the authors noted that the genitofemoral nerve was the nerve at most risk in the third quartile. This nerve must be a consideration to the surgeon as given its sensory function it will not be recognized by EMG and can be easily injured. This "safe entry zone" should not be considered universal, and as previously discussed, significant variation in patient anatomy may be present. Ultimately visual inspection and neuromonitoring are critical in minimizing risk to traversing nerves. In general, triggered EMG thresholds below 5 mA indicate direct contact, 5–10 mA indicate that the stimulation is in close proximity, and 11 mA indicates a farther distance from the lumbar plexus (Uribe et al. 2010b).

Pre-psoas

The key difference of the lateral pre-psoas approach is the intent of docking instrumentation between the psoas muscle and the great vessels. Due to the more anterior location on the vertebral body, there is a higher risk to the great vessels anteriorly, and it is frequently cited at a rate similar to the anterior approaches. Currently existing literature demonstrates a rate of vascular complication cited from 1.1% to 2.8% with damage to segmental arteries being the most common complications (Xu et al. 2018). Conversely, the risk of injury to the lumbar plexus is lower because the psoas is not blindly traversed. Determination of the operative window is made by preoperative planning and intraoperative visual and fluoroscopic inspection and dissection. Neuromonitoring is not necessary for this approach but can be considered.

Procedural Details

Surgical Positioning

Proper positioning is essential for successful lateral lumbar interbody fusion. The patient should be placed in the lateral decubitus position with the left side up. Right-sided approach may be considered, but this is generally discouraged due to increased risk of injuring the relatively thin-walled inferior vena cava during manipulation. If such an approach is undertaken, a trans-psoas corridor should be considered to decrease risk of IVC injury. Additionally, lateral jack-knife position may be used to improve access and visualization in certain cases, but this should be avoided if possible to avoid transient neurologic deficits (Molinares et al. 2016). An axillary roll is placed to avoid brachial plexus injury. Care should be taken to position the patient perpendicular to the floor. The fluoroscope is then brought into the field, and minor table adjustments are used to obtain a perpendicular lateral view of the target disc. Similarly, the flouroscope should be easily maneuverable to obtain a clear orthogonal AP view of the disc. Alternatively, computerized stereotactic navigation may be used, in which case the registration pin is placed into the iliac crest projecting posteriorly after prepping and draping. A small amount of hip flexion may be used to relax the psoas, which also serves to position the L4 and L5 nerve roots more posteriorly. At this time neuromonitoring (EMG) may be attached. If approaching the vertebral column using a trans-psoas approach, neuromonitoring should be used to avoid the risk of nerve injury while traversing the psoas. The patient's abdomen and flank should be prepped and draped widely despite the plan for a small incision. This will allow the laparotomy incision to be enlarged in the case of difficulty with dissection or complication.

Incision and Retroperitoneal Dissection

Under fluoroscopic or navigation guidance, the intervertebral disc of interest is identified before marking its caudocranial and anteroposterior projections on the skin. For the trans-psoas approach, a 4 cm incision is centered over the disc of interested and oriented obliquely (Fig. 1). If approaching anterior to psoas, the incision should be positioned more anteriorly from the center of the disc space (approximately 5 cm) to facilitate psoas mobilization and vertebral body visualization. The external oblique fascia is then sharply divided, and splitting of the external, internal, and transversalis abdominal musculature is performed using a Kelly clamp or bluntly. The underlying transversalis fascia is identified and divided before entering the retroperitoneal fat pad. Using a gloved index finger, the fat pad is gently dissected from the transversalis fascia before advancing more medially and posteriorly and along the anterior boarder of the quadratus lumborum to palpate the transverse process of the vertebral body (Fig. 2). After palpating the transverse process, blunt dissection is used to retract the peritoneal contents anteriorly to identify the vertebral disc space. Fluoroscopy is then used to confirm the correct intervertebral disc level.

Retractor Positioning

Trans-psoas

Fluoroscopy or navigation is used to localize the planned position to dock the retractor in the disc space. This is done by placing a k-wire in the disc space and using serial dilation to split the psoas muscle fibers. Neuromonitoring (triggered and free-running EMG) is monitored as each dilator and eventually the retractor blades are advanced. The electrical contacts are different for each company and should be studied and understood prior to surgery to evaluate the direction of stimulation. Typically, one small area of each dilator will have exposed uninsulated metal, and stimulation can proceed in quadrants to look for EMG firing. This can help the surgeon determine the direction of any at-risk nerves and reposition the retractor accordingly. If the EMGs demonstrate irritation, the retractor can be repositioned away from the direction of nerve root firing. The retractor blades can be pinned into the vertebral bodies above and below the disc space firmly into position. An ideally placed retractor will be overlying the disc at about the anterior 1/2 of the disc space, parallel to the endplates and in the coronal plane (Fig. 3). Fluoroscopy should be used to verify this position.

Pre-psoas

In the pre-psoas approach, the psoas is mobilized posteriorly for exposure of the ideal operative window. This space need only be slightly wider than the planned implant. Self-retaining retractors are then placed to retract the abdominal contents and psoas. The retractors can be rotated and slid slightly above the disc space to allow the disc prep tools and implants to be positioned in the coronal plane. A second retractor is placed medially to protect the peritoneum and great

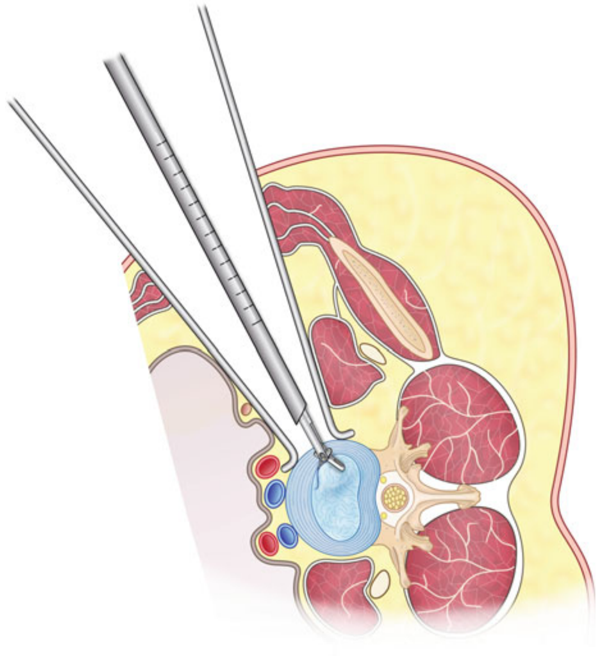

Fig. 3 In the pre-psoas approach, instrumentation is docked at the anterolateral disc space and a small annulotomy is performed followed by complete discectomy. (Reprinted with permission, University of Wisconsin © 2018. All Rights Reserved)

vessels, and if needed, a third retractor can be placed in the caudal aspect of the incision to protect peritoneal contents. Various retractor setups are available. This can also be done with handheld retractors if desired.

Disc Preparation and Implant Placement

An annulotomy is then performed followed by complete discectomy and removal of the cartilaginous endplates. This will ensure that a large surface area is available for effective fusion. Care should also be taken to bilaterally release the annulus to avoid coronal imbalances after implant placement. This may be performed by rotating a Cobb across the distal annulus of the disc space (Orita et al. 2017). Care should be taken to maintain a coronal trajectory. Failure to work in the coronal plane can lead injury to the vasculature anteriorly or neural elements posteriorly. The disc space is then sequentially distracted using spacers until the ideal height is reached. A lordotic cage filled with graft is then placed and positioned parallel to the disc space (Fig. 4) on the AP view and in line with the posterior aspect of the vertebral bodies on the lateral view. To avoid inserting the cage in a rotated alignment on the lateral view, the trials and rasps should be placed so that they are aligned with the posterior aspect of the vertebral bodies, allowing the cage to simply follow the created path.

Ideal implant placement involves adjusting the midpoint of the cage to the center of the vertebral body on AP view and between the anterior and middle-third on lateral view. Implant placement in the trans-psoas approach is directly perpendicular to the vertebral body along the planned trajectory. However, special attention needs to be used to place pre-psoas implants. The pre-psoas implant is placed obliquely from the 10 o’clock position on the disc, advanced 1/2 way into the disc space, and then the handle is rotated posteriorly perpendicular to the OR table to place it across the disc space. This is sometimes called the “orthogonal maneuver.”

The surgical field is then copiously irrigated, and meticulous hemostasis is achieved before removal of the self-retaining retractor and wound closure. The surgical corridor should be inspected for any injury to the peritoneum or retroperitoneal structures.

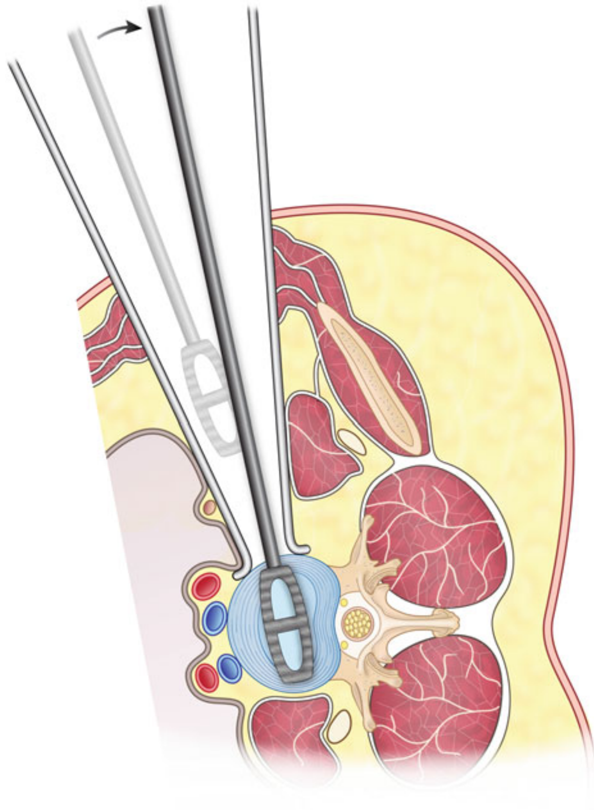

Fig. 4 Illustration demonstrating interbody graft placement using an pre-psoas approach. Ideal graft placement is midline on the lateral view and parallel to the disc space. (Reprinted with permission, University of Wisconsin © 2018. All Rights Reserved)

Posterior Instrumentation and Fusion

Posterior instrumentation can be considered to achieve a stable construct and increase the likelihood of fusion. This may be performed in multiple ways, but unless otherwise contraindicated, we prefer repositioning the patient in a prone position and performing bilateral percutaneous pedicle screw fixation using either fluoroscopic or stereotactic guidance.

Pre-psoas L5–S1

This is an advanced surgical technique but the pre-psoas approach does allow access to the L5–S1 level. This is performed by using a more anterior and medial incision and carefully docking the retractors between the bifurcation of the aorta and vena cava. An annulotomy is then performed, and discectomy and endplate preparation are completed. An anterior interbody cage is then implanted using a specially designed oblique introducer. Centering the implant can be challenging because of this oblique trajectory.

Complications and Their Management

Complications of the lateral approach are similar to those seen with ALIF with major complications related to damage of surrounding vascular, visceral, and neurologic structures. Yet, because there is generally no retraction of major vascular structures in the lateral approach, large series have reported no vascular or intraoperative injuries (Rodgers et al. 2011). If a vascular injury is identified, the first step is to obtain temporary control of the bleeding. This is often done using pressure from a kittner, suction, or sponge stick. If it is a large injury, then anesthesia should be notified to have blood products prepared to be administered. The second step will be to obtain improved access by making the incision larger. The third step will be to get adequate visualization of the injury. Primary repair can be attempted. Typically, prolene suture is used to suture vessels. Venous injuries must be repaired with care as the thin walls of the vessel can often tear. At any point, a vascular or general surgery consultation is encouraged to be obtained.

Other major complications include injury to the exiting nerve roots, particularly the L4 root. Permanent motor deficits have been reported between 0.7% and 3.4% (Knight et al. 2009) (Rodgers et al. 2011). Yet, when compared to other approaches, there is a high rate of transient groin and thigh pain after lateral approach which ranges from 10% up to 30%. These transient injuries, often hyperalgesia in the distribution of the iliohypogastric or ilioinguinal cutaneous nerves, are likely due to a combination of stretch and compression injury during the approach and retraction during surgery. Trans-psoas approaches are generally associated with higher complications rates (32.8%) versus oblique psoas-sparing approaches (13.5%) due to a higher likelihood of encountering the lumbar plexus during muscle dissection (Abe et al. 2017). Hip flexor weakness has also been reported and relates to manipulation of the psoas.

If the peritoneum is torn or injured, this is not typically a serious complication. Inspection should be performed to verify that no intestinal injury has occurred as this can be life-threatening if not identified. The peritoneum can be stitched closed with absorbable suture to avoid herniation of intestines. The surgery can continue.

If the intestines or abdominal organs are injured, then general surgery should be consulted for repair. Strong consideration should be given to aborting the procedure as the infection risk is very high in this situation. It can be helpful to have the patients undergo a bowel preparation prior to the surgery in order to minimize spillage of visceral contents, decrease likelihood of infection in case of incidental enterotomy, and increase the rate of repair.

Ureter injury is uncommon, but if it is encountered, then a urologist should be consulted to repair the ureter. The risks and benefits of proceeding should be weighed. Urine is typically sterile so the infection risk should be lower compared to intestinal injury.

As with ALIF, there is a risk of incisional hernia. If this occurs, then a referral to general surgery for repair is warranted.

Limitation of the parallel trajectory of the cage relative to the disc space secondary to a high-riding iliac crest is not technically a complication. However, it is often encountered at the L4–L5 level. In these cases, the senior author has proceeded with a discectomy without violating the contralateral annulus and placed a shorter cage to avoid neural compression in the canal or neural foramen.

Another key consideration when comparing anterior interbody to lateral interbody fusion is the risk of subsidence, which is defined as the potential loss of height within the neural foramen following indirect decompression with an interbody graft. While the gold standard for reducing the risk of subsidence is the anterior interbody fusion with an average of 10% risk of any subsidence without any events of neurologic consequence, both LLIF and OLIF have significant risks of subsidence and are important considerations with approach. Stand-alone LLIF has been shown to have subsidence rates of up to 30% when using standard 18 mm grafts (Marchi et al. 2013).

Conclusions

The lateral lumbar interbody fusion is a useful technique for the spine surgeon to have in his/her armamentarium. The keys to performing this technique safely and effectively are appropriate patient selection, safe lateral positioning, appropriate targeting of disc space with fluoroscopy or computerized stereotactic navigation, careful dissection and retractor placement to identify and avoid injury to intraperitoneal contents or pre-vertebral vascular structures, and aligning the tools to prepare the disc space and implant the graft in the coronal plane. If performing a trans-psoas approach, then neuromonitoring (triggered and free-running EMG) should be used to limit nerve injury. The outcomes of this procedure are similar to anterior lumbar interbody fusion but with less muscular dissection because of the lateral trajectory.

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