Chapter

Advancements in Minimally Invasive Lateral Interbody Fusion

Ronald Sahyouni, Luis D Diaz-Aguilar and Donald Blaskiewicz

Abstract

Extreme lateral interbody fusion (XLIF) is a popular surgical technique to address a wide variety of spinal pathologies. The purpose of this chapter is to explore the XLIF procedure, including indications for its use, post-fusion operative outcomes, intraoperative considerations, and advantages and disadvantages over similar fusion techniques.

Keywords: spinal fusion, extreme lateral interbody fusion, lateral lumbar interbody fusion, minimally invasive spine surgery, lumbar spine surgery

1. Introduction

Instrumented fusion of the spine is a proven method for treating a variety of spinal pathologies, such as deformity, instability and iatrogenic instability. Historically, instrumented fusion has been an open procedure, with various approaches to the spinal column including anterior lumbar interbody fusion (ALIF), posterior lumbar interbody fusion (PLIF), transformainal lumbar interbody fusion (TLIF), and posterior intertransverse fusion (PLF) [1–8]. However, advancements in minimally invasive surgery (MIS) have changed the landscape of instrumented spinal fusion procedures, and the focus of contemporary clinical practice emphasizes MIS fusion techniques because of their lower rate of complications, shorter recovery time, smaller incisions, and reduced intraoperative blood loss [9].

Extreme lateral interbody fusion (XLIF [NuVasive, San Diego, CA, USA]) is a novel minimally invasive technique in which the disc space is accessed laterally using a lateral transpsoatic approach [10]. The XLIF approach, which was introduced by Pimenta in 2001 and further developed in the same decade [11, 12], has been successfully shown to treat degenerative disc disease (DDD), deformity, trauma, tumor, and infection [13]. The purpose of this chapter is to explore the XLIF procedure, including indications for its use, post-fusion operative outcomes, intraoperative considerations, and advantages and disadvantages over similar fusion techniques.

2. Surgical terminology

While the MIS lateral interbody fusion technique is referred to as XLIF in this chapter, several other names exist for the same surgery. As of late, a general name for the surgery, lateral lumbar interbody fusion (LLIF), has emerged and increased in popularity within the literature [14, 15]. Similarly, comparable industry-sponsored surgical techniques have been coined, including the direct lateral interbody fusion (DLIF [Medtroinic, Memphis, TN, USA]) [15]. Although the term XLIF is chosen to described the MIS lateral interbody fusion technique in this chapter, it is important for readers to understand that the same surgical technique may be referenced with other names in the larger scope of the literature.

3. Anatomy

The XLIF approach is a retroperitoneal, transpsoas approach to the spinal column. The retroperitoneal space bordered by the posterior part of the transversalis fascia and the posterior parietal peritoneum, and encompasses critical organs including kidneys, adrenal glands, ureters, ascending, and descending segments of the colon, neurovascular structures including the aorta, inferior vena cava (IVC), lumbar plexus, and sympathetic trunk. In addition, spinal levels located in the posterior retroperitoneal space include T12 to the sacrum, and the psoas muscle is also located within this span.

Several muscular structures and layers are traversed during the XLIF procedure. First, the lateral abdominal muscle layers, starting superiorly from the external abdominal oblique, internal abdominal oblique, transversus abdominis, and rectus abdominis muscles, must be carefully dissected. Critical neurological structures to be mindful of during dissection include the iliohypogastric and ilioinguinal branches of L1, which supply sensation to skin over the lateral gluteal and hypogastric regions.

The psoas muscle, which is the major muscle encountered during the XLIF approach, acts as a hip abductor, lateral rotator, and flexor. The superficial part and origin of the psoas muscle begins at the T12 and L1 to L4 vertebrae, overlying the lumbar plexus. The deep part of the psoas muscle takes origin from the transverse processes of lumbar vertebrae L1 to L5, and the entire psoas muscle crosses the pelvic brim and inserts on the lesser trochanter of the femur. Of particular anatomical importance is the femoral nerve which is derived from the anterior rami of nerve roots, L2, L3 and L4. The femoral nerve is the largest branch of the lumbar plexus. The femoral nerve lies within the posterior 1/4th of the disc space at L4/5. Intraoperative nerve monitoring is helpful in reducing the risk of nerve injury [16, 17].

Furthermore, the diaphragm, and associated lumbar attachments of the right and left crura, pose an anatomical consideration during an XLIF procedure. Namely, adequate mobilization of the diaphragm around the thoracolumbar junction allows for improved disc exposure and a wider window through which a lateral XLIF corpectomy may be performed [18]. In addition, angled approaches may allow for successful XLIF completion with avoidance of the diaphragm.

4. Indications for XLIF

There are multiple indications for the XLIF procedure, including [19]:

- Spondylolisthesis
- Herniated Disc
- DDD
- Post-laminectomy instability

- Adjacent Segment Disease
- Degenerative Scoliosis
- Thoracic disc herniations
- Need for corpectomy for trauma or tumor

Oftentimes, the XLIF surgical approach is considered in patients with symptoms refractory to other treatments, including physical therapy, pain medication, and steroid injections. Additionally, specific spinal levels are best treated with the XLIF technique. High-risk patients with complicated histories may further benefit from XLIF surgery due to its minimally invasive nature. Minimal blood loss, tissue damage, and post-operative discomfort make it a viable option for complicated patients.

Furthermore, several patient conditions exclude the consideration of XLIF as a viable surgical technique. These conditions include, but are not limited to:

- Fusion below the pelvic brim (L5-S1), which inhibits access to the disc space from the lateral position
- Bilateral retroperitoneal scarring
- Complicated and/or high-grade spondylolisthesis
- Low riding L4-L5 space, with limited access to the disc space
- Spinal deformities resulting in significant spinal rotation
- Poor bone stock due to osteoarthritis, reducing the probability of successful vertebral fusion

5. Procedure

Following endotracheal anesthesia and intravenous line placement, the patient is positioned on their side in a true 90-degree lateral decubitus position [11].The side through which the XLIF is performed is determined based on anatomical and clinical consideration. X-ray imaging is performed using a cross-table anterior–posterior (AP), and lateral technique to locate and confirm the disc of interest, and plan the surgical incision. The skin is aseptically treated and patient's spine is placed in flexion to achieve sufficient distance between the ribcage and iliac crest. Next, the pathway for instrumentation is calculated using a k-wire and lateral fluoroscopic imaging to identify the mid-position of the lumbar disc. This position is marked on the patient's lateral side at the level of the diseased disc and will serve as the working portal throughout the operation [11].

Prior to the introduction of surgical instruments, a second mark is made posterior to the working portal at the intersection of the erector spinae and abdominal oblique muscles. A 3–4 cm lateral incision is made here, large enough to allow the entry of the surgeon's index finger, which will be inserted anteriorly and advanced until the retroperitoneal space and peritoneum are identified [11]. Placement of the surgeon's finger will help protect the peritoneum, in which the visceral organs are encased, from injury while instruments are passed into and out of the working portal.

Next, the primary 3–4 cm incision is made at the mark of the working portal and the initial tubular dilator is introduced laterally, with the index finger guiding it towards the psoas muscle and away from neurovasculature and the peritoneal sac. Electromyography (EMG) is performed at the psoas muscle to steer clear of lumbar nerve roots and branches of the lumbar plexus. The psoas muscle is delicately parted between the middle and anterior third of the muscle, allowing for direct manipulation of the spine with minimal risk of damage to nervous structures and large vessels coursing anterior to the operative corridor. Additional tubular dilators are introduced to further increase the dimension of the working portal, throughout which nerve monitoring and X-ray imaging are continued to ensure safety and precision at the level of the damaged disc. Once the working portal is dilated to an appropriate diameter, a retractor is inserted and expanded in a cranio-caudal direction to the appropriate aperture [11]. The aperture of the retractor may be adjusted periodically during the operation on an as-needed basis to provide appropriate visualization and access to the spinal column. A light and camera may then be inserted and fusion may now begin.

At this point, discectomy is performed in a standard fashion and using standard surgical instruments. The diseased disc is removed with preservation of the posterior annulus, and the interbody implant is able to be accommodated in the space, resting on the lateral margins of the epiphyseal ring to increase end plate support [11]. To close the surgical site, the operative site is irrigated and hemostasis is achieved. The facial and subcutaneous layers are sutured closed, with some skin glue to close the most superficial layers. Depending on the individual patients' status, additional support including pedicle screws, plates, or rods may be inserted to stabilize the patient.

6. Intraoperative risks

The XLIF surgical approach has been associated with a unique set of complications involving multiple neurovascular structures and visceral organs that may be iatrogenically damaged during soft tissue dissection or surgical instrumentation.

6.1 Nerve injury

Nerve injury is among the most commonly cited complications following XLIF procedures. Recent reviews have suggested that neurological injury - specifically ipsilateral sensorimotor deficits of the groin and/or thigh - may be experienced transiently by 30–40% of patients postoperatively and permanently by 4–5% of patients [15, 20]. Structures that may be damaged during the surgical approach and instrumentation include the sympathetic chain located in the lateral aspect of vertebral body, the lumbosacral plexus containing the genitofemoral nerve located on the anterior surface of psoas muscle, and the superior hypogastric plexus.

The femoral branch of the genitofemoral nerve provides sensation to the scrotum in males, mons pubis in females, and anterior thigh in both sexes while the genital branch provides motor innervation to the cremaster muscle in males. Radiographic studies have demonstrated the close proximity of the genitofemoral nerve to the L2/L3 disc space [21] while cadaveric studies suggest anatomic variation in the course of the genitofemoral nerve in 40–50% of individuals [22]. These anatomical factors place the nerve at high risk of trauma with no zone of absolute safety during the XLIF approach [23], so surgeons must carefully navigate the surgical interval to avoid neurological injury. Furthermore, prolonged muscle retraction time over 20–40 minutes per level has been shown to greatly increase the risk of nerve injury [24], and electromyographic monitoring has been shown to reliability predict nerve dysfunction [25], highlighting the importance of reducing operative time. Newer retractor systems and more refined surgical techniques may eventually decrease the incidence of retractor-related nerve damage [26, 27].

More recent studies have also demonstrated small (1.7–4.8%) risks of femoral and obturator nerve neurapraxia and/or axonotmesis in the immediate post-operative period, though full recovery is expected within 3 months [28, 29]. Of note, femoral nerve injury is almost exclusively observed at the L4-L5 lumbar levels as anatomic studies have demonstrated that the femoral nerve lies more proximal to the ideal discectomy site at L4-L5, placing it at increased risk within that region [30, 31]. Several studies have also noted the risk of contralateral femoral nerve injury secondary to overzealous endplate removal and osteophyte distraction [32, 33].

Additional nervous structures that may be damaged intraoperatively include the ilioinguinal, iliohypogastric, and lateral femoral cutaneous nerves that course through the retroperitoneal space and lateral abdominal wall, though the literature is scarce on these complications. Retrograde ejaculation is also theoretically possible if there is damage to the superior hypogastric plexus, but there has yet to be a report of this complication following XLIF. Finally, bowel and bladder dysfunction may be a rare complication associated with lumbosacral plexus injury.

6.2 Vascular injury

Vascular injury is extremely rare in XLIFs compared to approaches such as the ALIF, as great vessels such as the aorta and iliac arteries are avoided. However, dissection of segmental arteries can result in serious complications that may occur during or shortly after an XLIF procedure. In one case, a large retroperitoneal hematoma was detected five days following an L3-L4 and L4-L5 XLIF [34]. Arteriography identified active bleeding from the L2 segmentary artery as the underlying etiology. This branch was promptly embolized with fibre coils, and the patient suffered no further complications. A similar case by Santillan et al. described the development of a retroperitoneal hematoma 48 hours after an uneventful L2-L3 XLIF [35]. An angiogram showed iatrogenic arterial wall disruption of the L2 lumbar artery and a traumatic pseudoaneurysm, both of which were successfully embolized with no further sequelae. Finally, a fatal case of bleeding was reported by Assina et al. in a 50-year old patient undergoing XLIF for an L4-L5 degenerative disc [36]. Imaging showed that the anterior detachable blade tip (Scoville type retractor) had transected the right common iliac vein and was within the lumen of the left common iliac vein. Furthermore, multiple perforations along the distal IVC were noted. Despite 29 units of packed red blood cells, multiple other heroic measures, and a 4-week intensive care unit stay, the patient developed a retroperitoneal abscess with bacteremia that ultimately led to hemodynamic instability and fatal multiple organ failure secondary to septic shock.

6.3 Visceral structures

Injury to non-neurovascular structures is uncommon in the setting of XLIFs and described primarily in case reports. The ureter traverses the retroperitoneal space close to XLIF surgical corridor in approximately 16% of cases [37] and may be damaged by retractors or retroperitoneal dissection particularly at the L2-L3 level [38], though no cases of urological injury have been reported on XLIFs specifically. However, ureteral complications have been reported in several patients undergoing OLIF, which utilizes a similar surgical approach to the XLIF [39–42].

Peritoneal damage following XLIF is exceedingly rare and has been described in just a few case reports. Balsano et al. reported an iatrogenic perforation of the splenic curvature of the colon following an L3-L4 and L4-L4 XLIF for degenerative disc disease [43]. The patient experienced peritonitis and underwent an exploratory laparotomy that identified the colonic perforation, and a colostomy was maintained for 3 months after which the patient fully recovered. Tormenti et al. described a cecal perforation during the transpsoas approach of an XLIF for treating adult degenerative thoracolumbar scoliosis [44]. The patient underwent an emergency exploratory laparotomy and segmental bowel resection and recovered uneventfully.

Finally, delayed incisional hernias have been described following XLIF. Plato-Bello et al. reported the development of an abdominal pseudohernia requiring surgical repair 5 months after an uneventful L3-L4 LLIF [45]. Similarly, Gundanna and Shah presented a patient who exhibited herniation of abdominal contents through the original incision site 2 years after an L3-L4 XLIF and required laparoscopic hernia repair surgery [46].

7. Postoperative course and recovery

The postoperative course of XLIF surgery has been shown to minimize complications and recovery time. A prospective study of 600 patients treated with XLIF surgery revealed an average inpatient length of stay (LOS) of 1.21 days, and empirical evidence suggests that many patients may be able to ambulate within a day of the operation [47]. A similar study with a smaller cohort of 84 patients demonstrated a mean LOS of 2.6 days, with robust evidence of successful fusion on follow-up imaging [48].

On a comparable note, patient pain outcomes have been shown to significantly improve following the XLIF procedure. Improvements in two independent pain scoring metrics, the first being the visual analog scale (VAS) and the second being the Oswestry Disability Index (ODI), have been demonstrated in the literature. Specifically, a 2010 study by Youssef et al. reported a 77% and 56% increase in VAS and ODI respectively following XLIF at one-year follow-up [48]. Similarly, a 2011 study by Rodgers et al. demonstrated a 65% immediate improvement in VAS following XLIF, with 86.7% of patients satisfied with their operation at one-year follow-up [47]. The findings of both studies, with respect to improvements in patient-reported pain outcomes following XLIF, have been explored further and confirmed in several contemporary studies with similar conclusions [49, 50].

However, a major complication to consider following XLIF is graft subsidence, which threatens the long-term efficacy of the procedure. Several studies have demonstrated high rates of cage subsidence, as defined as >2 mm of cage settlement into the vertebral body, following the XLIF procedure [51, 52]. In many of these cases, 18-mm-wide and 22-mm-wide cages are used, and although previous studies have demonstrated their relative safety and efficacy, the rates of reported cage subsidence at these dimensions is suboptimal. A recent study by Lang et al. demonstrated that 26-mm-wide may reduce rates of cage subsidence while achieving excellent outcomes on both radiologic and clinical follow-up evaluation [53].

8. Advantages and disadvantages over similar techniques

The XLIF is a relatively new technique that is being quickly added into the toolkits of spine surgeons around the world. However, despite the rapid adoption of this surgical approach, there are both advantages and disadvantages to this technique compared to conventional approaches such as ALIF, TLIF, PLIF, and OLIF.

8.1 Advantages

One of the primary advantages to MIS surgery is the usage of smaller incisions compared to the large posterior or anterior approaches, resulting in reduced soft tissue damage, faster recovery times, and less postoperative pain. Multiple studies have described average hospital stays of just over 1 day and relatively few complications with XLIF [47, 49, 54, 55]. Additionally, unlike the ALIF, the XLIF is associated with less intraoperative blood loss [48] and lower risk of vascular injury, as major vessels such as the aorta are altogether avoided. For this reason, the XLIF conveniently eliminates the need for a vascular surgeon to either perform the ALIF approach or be on standby, which may translate to significant cost-savings. Furthermore, while there is increased risk of vascular damage in obese patient undergoing ALIF, this complication can be largely avoided by using the XLIF [56]. The XLIF also theoretically places the superior hypogastric plexus at risk, but there have been no cases of retrograde ejaculation compared to ALIF [57, 58]. Finally, the XLIF has been radiographically shown to have high rates of fusion, patient satisfaction, and patient-reported outcomes in several large studies [49, 54].

8.2 Disadvantages

Several reviews have noted that XLIFs are associated with a far higher rate of lumbar nerve root/plexus injury compared to alternatives [59], though other studies suggest that these rates are statistically comparable in XLIFs and ALIFs [60]. Furthermore, the XLIF approach requires dissection of the psoas muscle unlike in similar alternatives such as the OLIF or ALIF. The transpsoas approach leads to traumatic soft tissue damage, and coupled with the proximity of the genitofemoral nerve, likely explains the prevalence of transient thigh numbness/weakness. However, this complication has been largely shown to be temporary and clinically insignificant. Smaller studies have cited higher rates of prolonged hospital stay or complications [61], but these findings are out of the norm and may reflect surgeon inexperience or the learning curve associated with newer MIS techniques. Finally, studies have suggested that XLIFs are susceptible to intervertebral cage settling, which may lead to poorer long-term surgical correction and necessitate wider cages [62]. Even so, however, XLIFs are at significant risk of anterior and lateral protrusion, suggesting the need to reduced cage length whenever possible [63]. The XLIF is still a procedure in its early stages of implementation and higher quality evidence is needed to further differentiate it from alternative surgical approaches.

9. Patient perceptions

While more research is needed to further quantify the advantages and disadvantages of XLIF compared to conventional approaches, patient perceptions and expectations play an important role in the utilization of this newer technique. Presently, no study has investigated the role and impact of patient requests and perceptions in the decision-making process for which specific surgical approach is ultimately performed for lumbar spine pathologies. However, a recent study conducted by Narain et al. [64] found that prospective spine surgery patients with degenerative spine disorders overwhelmingly preferred a minimally invasive approach. These patients perceived open surgery to be more painful, having a higher complication rate, having prolonged recovery time, more expensive, and requiring heavier sedation compared to MIS. While this study clearly suggests that offering minimally invasive procedures is a highly marketable skill for spine surgeons, it also highlights the importance of setting realistic patient expectations for the operative and postoperative course. Spine surgeons will need to attenuate patient perceptions in the clinic with unbiased discussions on the advantages and disadvantages of XLIF compared to alternative approaches in the joint decision-making process to ensure proper clinical management.

10. Conclusion

The presence of minimally invasive spine surgery techniques in all practice settings has greatly increased over the past decade and will likely continue to rise in popularity due to patient requests/perceptions, marketability of MIS procedures, improving technology, and increased surgeon comfort. As MIS spine procedures become a standardized part of spine training, it will be important to continue monitoring the long-term advantages and disadvantages of procedures such as the XLIF compared to conventional approaches. Far more research is needed to determine the role of MIS techniques in a spine surgeon's armamentarium and whether specific surgery-related risks are justified by improved surgical and patient-reported outcomes. In the meantime, spine surgeons offering MIS procedures will need to provide transparent information regarding these surgeries to their patients, setting the expectation that these newer techniques may not necessarily result in superior outcomes compared to classic approaches.

Author details

Ronald Sahyouni, Luis D Diaz-Aguilar and Donald Blaskiewicz*
Department of Neurosurgery, University of California, San Diego, United States

*Address all correspondence to: dblaskiewicz@health.ucsd.edu

References

[1] Kalanithi PS, Patil CG, Boakye M. National complication rates and disposition after posterior lumbar fusion for acquired spondylolisthesis. Spine . 2009;34(18):1963-1969.

[2] DiPaola CP, Molinari RW. Posterior lumbar interbody fusion. *J Am Acad Orthop Surg*. 2008;16(3):130-139.

[3] Carreon LY, Puno RM, Dimar JR 2nd, Glassman SD, Johnson JR. Perioperative complications of posterior lumbar decompression and arthrodesis in older adults. *J Bone Joint Surg Am*. 2003;85(11):2089-2092.

[4] Scaduto AA, Gamradt SC, Yu WD, Huang J, Delamarter RB, Wang JC. Perioperative complications of threaded cylindrical lumbar interbody fusion devices: anterior versus posterior approach. *J Spinal Disord Tech*. 2003;16(6):502-507.

[5] Rihn JA, Patel R, Makda J, et al. Complications associated with single-level transforaminal lumbar interbody fusion. *Spine J.* 2009;9(8):623-629.

[6] Sasso RC, Best NM, Mummaneni PV, Reilly TM, Hussain SM. Analysis of operative complications in a series of 471 anterior lumbar interbody fusion procedures. Spine . 2005;30(6):670-674.

[7] Dhall SS, Wang MY, Mummaneni PV. Clinical and radiographic comparison of mini--open transforaminal lumbar interbody fusion with open transforaminal lumbar interbody fusion in 42 patients with long-term follow-up. *J Neurosurg Spine*. 2008;9(6):560-565.

[8] Park P, Foley KT. Minimally invasive transforaminal lumbar interbody fusion with reduction of spondylolisthesis: technique and outcomes after a minimum of 2 years' follow-up. *Neurosurg Focus*. 2008;25(2):E16.

[9] Kim CH, Easley K, Lee J-S, et al. Comparison of Minimally Invasive Versus Open Transforaminal Interbody Lumbar Fusion. *Global Spine J.* 2020;10(2 Suppl):143S -150S.

[10] Quante M, Halm H. [Extreme lateral interbody fusion. Indication, surgical technique, outcomes and specific complications]. *Orthopade*. 2015;44(2):138-145.

[11] Ozgur BM, Aryan HE, Pimenta L, Taylor WR. Extreme Lateral Interbody Fusion (XLIF): a novel surgical technique for anterior lumbar interbody fusion. *Spine J.* 2006;6(4):435-443.

[12] He Q. The Extreme Lateral Interbody Fusion (XLIF): Its Today and Tomorrow. *J Spine*. 2013;03(01). doi:10.4172/2165-7939.1000e112

[13] Pimenta L, Oliveira L, Schaffa T, Coutinho E, Marchi L. Lumbar total disc replacement from an extreme lateral approach: clinical experience with a minimum of 2 years' follow-up. *J Neurosurg Spine*. 2011;14(1):38-45.

[14] Mobbs RJ, Phan K, Malham G, Seex K, Rao PJ. Lumbar interbody fusion: techniques, indications and comparison of interbody fusion options including PLIF, TLIF, MI-TLIF, OLIF/ATP, LLIF and ALIF. *J Spine Surg*. 2015;1(1):2-18.

[15] Hah R, Kang HP. Lateral and Oblique Lumbar Interbody Fusion-Current Concepts and a Review of Recent Literature. *Curr Rev Musculoskelet Med*. Published online June 22, 2019:305-310.

[16] Tohmeh, A.G., W.B. Rodgers, and M.D. Peterson, *Dynamically evoked, discrete-threshold electromyography in the extreme lateral interbody fusion approach.* J Neurosurg Spine, 2011. **14**(1): p. 31-37.

[17] Uribe, J.S., et al., *Defining the safe working zones using the minimally invasive*

lateral retroperitoneal transpsoas approach: an anatomical study. J Neurosurg Spine, 2010. **13**(2): p. 260-266.

[18] Smith WD, Dakwar E, Le TV, Christian G, Serrano S, Uribe JS. Minimally invasive surgery for traumatic spinal pathologies: a mini-open, lateral approach in the thoracic and lumbar spine. Spine . 2010;35 (26 Suppl):S338-S346.

[19] Arnold PM, Anderson KK, McGuire RA Jr. The lateral transpsoas approach to the lumbar and thoracic spine: A review. *Surg Neurol Int*. 2012;3(Suppl 3):S198-S215.

[20] Hijji FY, Narain AS, Bohl DD, et al. Lateral lumbar interbody fusion: a systematic review of complication rates. *Spine J.* 2017;17(10):1412-1419.

[21] He L, Kang Z, Tang W-J, Rong L-M. A MRI study of lumbar plexus with respect to the lateral transpsoas approach to the lumbar spine. *Eur Spine J.* 2015;24(11):2538-2545.

[22] Anloague PA, Huijbregts P. Anatomical variations of the lumbar plexus: a descriptive anatomy study with proposed clinical implications. *J Man Manip Ther*. 2009;17(4):e107-e114.

[23] Banagan K, Gelb D, Poelstra K, Ludwig S. Anatomic mapping of lumbar nerve roots during a direct lateral transpsoas approach to the spine: a cadaveric study. Spine . 2011;36(11):E687-E691.

[24] O'Brien JR. Nerve Injury in Lateral Lumbar Interbody Fusion. *Spine* . 2017;42 Suppl 7:S24.

[25] Uribe JS, Isaacs RE, Youssef JA, et al. Can triggered electromyography monitoring throughout retraction predict postoperative symptomatic neuropraxia after XLIF? Results from a prospective multicenter trial. *Eur Spine J.* 2015;24 Suppl 3:378-385.

[26] Sedra F, Lee R, Dominguez I, Wilson L. Neurological complications using a novel retractor system for direct lateral minimally invasive lumbar interbody fusion. *J Clin Neurosci*. 2016;31:81-87.

[27] Nunley P, Sandhu F, Frank K, Stone M. Neurological Complications after Lateral Transpsoas Approach to Anterior Interbody Fusion with a Novel Flat-Blade Spine-Fixed Retractor. *Biomed Res Int*. 2016;2016:8450712.

[28] Abel NA, Januszewski J, Vivas AC, Uribe JS. Femoral nerve and lumbar plexus injury after minimally invasive lateral retroperitoneal transpsoas approach: electrodiagnostic prognostic indicators and a roadmap to recovery. *Neurosurg Rev*. 2018;41(2):457-464.

[29] Cahill KS, Martinez JL, Wang MY, Vanni S, Levi AD. Motor nerve injuries following the minimally invasive lateral transpsoas approach. *J Neurosurg Spine*. 2012;17(3):227-231.

[30] Benglis DM, Vanni S, Levi AD. An anatomical study of the lumbosacral plexus as related to the minimally invasive transpsoas approach to the lumbar spine. *J Neurosurg Spine*. 2009;10(2):139-144.

[31] Davis TT, Bae HW, Mok JM, Rasouli A, Delamarter RB. Lumbar plexus anatomy within the psoas muscle: implications for the transpsoas lateral approach to the L4-L5 disc. *J Bone Joint Surg Am*. 2011;93(16):1482-1487.

[32] Grimm BD, Leas DP, Poletti SC, Johnson DR 2nd. Postoperative Complications Within the First Year After Extreme Lateral Interbody Fusion: Experience of the First 108 Patients. *Clin Spine Surg*. 2016;29(3):E151-E156.

[33] Papanastassiou ID, Eleraky M, Vrionis FD. Contralateral femoral nerve compression: An unrecognized complication after extreme lateral

interbody fusion (XLIF). *J Clin Neurosci*. 2011;18(1):149-151.

[34] Peiró-García A, Domínguez-Esteban I, Alía-Benítez J. Retroperitoneal hematoma after using the extreme lateral interbody fusion (XLIF) approach: Presentation of a case and a review of the literature. *Rev Esp Cir Ortop Traumatol*. 2016;60(5):330-334.

[35] Santillan A, Patsalides A, Gobin YP. Endovascular embolization of iatrogenic lumbar artery pseudoaneurysm following extreme lateral interbody fusion (XLIF). *Vasc Endovascular Surg*. 2010;44(7):601-603.

[36] Assina R, Majmundar NJ, Herschman Y, Heary RF. First report of major vascular injury due to lateral transpsoas approach leading to fatality. *J Neurosurg Spine*. 2014;21(5):794-798.

[37] Fujibayashi S, Otsuki B, Kimura H, Tanida S, Masamoto K, Matsuda S. Preoperative assessment of the ureter with dual-phase contrast-enhanced computed tomography for lateral lumbar interbody fusion procedures. *J Orthop Sci*. 2017;22(3):420-424.

[38] Davis TT, Hynes RA, Fung DA, et al. Retroperitoneal oblique corridor to the L2-S1 intervertebral discs in the lateral position: an anatomic study. *J Neurosurg Spine*. 2014;21(5):785-793.

[39] Quillo-Olvera J, Lin G-X, Jo H-J, Kim J-S. Complications on minimally invasive oblique lumbar interbody fusion at L2-L5 levels: a review of the literature and surgical strategies. *Ann Transl Med*. 2018;6(6):101.

[40] Lee H-J, Kim J-S, Ryu K-S, Park CK. Ureter Injury as a Complication of Oblique Lumbar Interbody Fusion. *World Neurosurg*. 2017;102:693.e7-e693.e14.

[41] Kubota G, Orita S, Umimura T, Takahashi K, Ohtori S. Insidious intraoperative ureteral injury as a complication in oblique lumbar interbody fusion surgery: a case report. *BMC Res Notes*. 2017;10(1):193.

[42] Abe K, Orita S, Mannoji C, et al. Perioperative Complications in 155 Patients Who Underwent Oblique Lateral Interbody Fusion Surgery: Perspectives and Indications From a Retrospective, Multicenter Survey. *Spine* . 2017;42(1):55-62.

[43] Balsano M, Carlucci S, Ose M, Boriani L. A case report of a rare complication of bowel perforation in extreme lateral interbody fusion. *Eur Spine J.* 2015;24 Suppl 3:405-408.

[44] Tormenti MJ, Maserati MB, Bonfield CM, Okonkwo DO, Kanter AS. Complications and radiographic correction in adult scoliosis following combined transpsoas extreme lateral interbody fusion and posterior pedicle screw instrumentation. *Neurosurg Focus*. 2010;28(3):E7.

[45] Plata-Bello J, Roldan H, Brage L, Rahy A, Garcia-Marin V. Delayed Abdominal Pseudohernia in Young Patient After Lateral Lumbar Interbody Fusion Procedure: Case Report. *World Neurosurg*. 2016;91:671.e13-e16.

[46] Gundanna M, Shah K. Delayed Incisional Hernia Following Minimally Invasive Trans-Psoas Lumbar Spine Surgery: Report of a Rare Complication and Management. *Int J Spine Surg*. 2018;12(2):126-130.

[47] Rodgers WB, Gerber EJ, Patterson J. Intraoperative and early postoperative complications in extreme lateral interbody fusion: an analysis of 600 cases. Spine . 2011;36(1):26-32.

[48] Youssef JA, McAfee PC, Patty CA, et al. Minimally invasive surgery: lateral approach interbody fusion: results and review. Spine . 2010;35(26 Suppl):S302-S311.

[49] Phillips FM, Isaacs RE, Rodgers WB, et al. Adult degenerative scoliosis treated with XLIF: clinical and radiographical results of a prospective multicenter study with 24-month follow-up. Spine . 2013;38(21):1853-1861.

[50] Ahmadian A, Verma S, Mundis GM Jr, Oskouian RJ Jr, Smith DA, Uribe JS. Minimally invasive lateral retroperitoneal transpsoas interbody fusion for L4-5 spondylolisthesis: clinical outcomes. *J Neurosurg Spine*. 2013;19(3):314-320.

[51] Marchi L, Abdala N, Oliveira L, Amaral R, Coutinho E, Pimenta L. Radiographic and clinical evaluation of cage subsidence after stand-alone lateral interbody fusion. *J Neurosurg Spine*. 2013;19(1):110-118.

[52] Marchi L, Abdala N, Oliveira L, Amaral R, Coutinho E, Pimenta L. Stand-alone lateral interbody fusion for the treatment of low-grade degenerative spondylolisthesis. *ScientificWorldJournal*. 2012;2012:456346.

[53] Lang G, Navarro-Ramirez R, Gandevia L, et al. Elimination of Subsidence with 26-mm-Wide Cages in Extreme Lateral Interbody Fusion. *World Neurosurg*. 2017;104:644-652.

[54] Rodgers WB, Gerber EJ, Patterson JR. Fusion after minimally disruptive anterior lumbar interbody fusion: Analysis of extreme lateral interbody fusion by computed tomography. *SAS J*. 2010;4(2):63-66.

[55] Deluzio KJ, Lucio JC, Rodgers WB. Value and cost in less invasive spinal fusion surgery: lessons from a community hospital. *SAS J*. 2010;4(2):37-40.

[56] Rodgers WB, Cox CS, Gerber EJ. Early complications of extreme lateral interbody fusion in the obese. *J Spinal Disord Tech*. 2010;23(6):393-397.

[57] Sasso RC, Kenneth Burkus J, LeHuec J-C. Retrograde ejaculation after anterior lumbar interbody fusion: transperitoneal versus retroperitoneal exposure. Spine . 2003;28(10):1023-1026.

[58] Winder MJ, Gambhir S. Comparison of ALIF vs. XLIF for L4/5 interbody fusion: pros, cons, and literature review. *J Spine Surg*. 2016;2(1):2-8.

[59] Epstein NE. More nerve root injuries occur with minimally invasive lumbar surgery, especially extreme lateral interbody fusion: A review. *Surg Neurol Int*. 2016;7(Suppl 3):S83-S95.

[60] Hrabalek L, Adamus M, Gryga A, Wanek T, Tucek P. A comparison of complication rate between anterior and lateral approaches to the lumbar spine. *Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub*. 2014;158(1):127-132.

[61] Knight RQ, Schwaegler P, Hanscom D, Roh J. Direct lateral lumbar interbody fusion for degenerative conditions: early complication profile. *J Spinal Disord Tech*. 2009;22(1):34-37.

[62] Tohmeh AG, Khorsand D, Watson B, Zielinski X. Radiographical and clinical evaluation of extreme lateral interbody fusion: effects of cage size and instrumentation type with a minimum of 1-year follow-up. Spine . 2014;39(26):E1582-E1591.

[63] Regev GJ, Haloman S, Chen L, et al. Incidence and prevention of intervertebral cage overhang with minimally invasive lateral approach fusions. Spine . 2010;35(14):1406-1411.

[64] Narain AS, Hijji FY, Duhancioglu G, et al. Patient Perceptions of Minimally Invasive Versus Open Spine Surgery. *Clin Spine Surg*. 2018;31(3):E184-E192.