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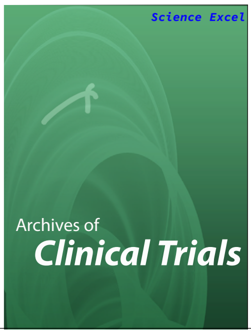

Research Progress of the Anatomical Structure of the Surgical Approach for Oblique Lumbar Interbody Fusion

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Abstract

Oblique Lumbar Interbody Fusion (OLIF) is a newly developed minimally invasive lumbar interbody fusion procedure used to treat a variety of degenerative lumbar spine diseases. The OLIF procedure has the advantages of less trauma, less bleeding, faster recovery, significant indirect decompression, large bone graft area, high fusion rate, and preservation of posterior column structures, but it needs to be performed under the condition of familiarity with the patient's anatomical approach to avoid injury to nerves, blood vessels, and other structures. In this paper, we review the new clinical advances in the application of anatomy for OLIF surgery in terms of the abdominal wall, blood vessels, lumbar major muscle, window between blood vessels and lumbar major muscle, nerves, and ureter.

Introduction

With the development of surgical technology, minimally invasive surgery has become the mainstream direction of surgery. Minimally invasive is not only a technique, but also a concept, and the meaning of minimally invasive is small trauma, not small incision. Oblique Lumbar Interbody Fusion (OLIF) was developed under this concept, and Mayer et al. [1] first proposed a minimally invasive technique via an anterolateral approach, and Silvestre et al. [2] introduced the term Oblique Lumbar Interbody Fusion in 2012.

The OLIF procedure involves a 4-cm-long skin incision in the lateral region of the abdomen parallel to the fibers of the external oblique muscle, followed by blunt separation of the external oblique, internal oblique, and transversus abdominis muscles in the direction of their fibers to access the retroperitoneal space, and placement of a retractor between the abdominal aorta and the anterior border of the psoas major muscle to establish surgical access [2-4]. Proficiency in anatomical structures is a prerequisite for the safe performance of the procedure. Although OLIF surgery has the advantages of less trauma, less bleeding, faster recovery, significant indirect decompression, large bone graft area, high fusion rate, and preservation of posterior column structures [2,5-7], complications such as vascular or nerve injury after OLIF have been reported from time to time in recent years [8]. Therefore, the anatomy of the OLIF approach has been studied by cadaveric anatomy or imaging such as CT and MRI.

Anatomical Structure

Abdominal wall

OLIF surgery is performed by making a small incision in the body projection corresponding to the center of the left intervertebral disc and bluntly separating the external oblique abdominal muscle, internal oblique abdominal muscle, and transverse abdominal muscle in the direction of the muscle fibers of each layer[3]. There are several arteries and nerves in between, including the posterior intercostal artery, the inferior costal artery, the deep rotor iliac artery, the superior abdominal wall artery, the inferior abdominal wall artery, the intercostal nerve, the inferior costal nerve, and the lateral branch of the 1st lumbar nerve [9], and these vascular nerves should be avoided as much as possible during surgery to prevent postoperative sensory abnormalities and abdominal wall paralysis.

Abdominal aorta and oblique corridor

The abdominal aorta begins at the aortic fissure on the septal muscle and proceeds forward to the 12th thoracic vertebra. It descends anterior to the lumbar vertebrae and aborts at the inferior border of the 4th lumbar vertebra or the 4th-5th lumbar disc, slightly to the left of the median line, dividing into the left and right common skeletal arteries. The psoas major muscle is long on both sides of the lumbar vertebrae and at the pelvic edge. Its proximal

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attachment points are structurally complex and include the anterior and inferior margins of all lumbar transverse processes. The psoas major has 5 finger-like projections, each originating from the 2 adjacent lumbar vertebrae and the intervertebral discs between them. The highest point of origin is at the inferior border of the 12th thoracic vertebra and the superior border of the 1st lumbar vertebra and the intervertebral discs between them. The lowest starting point was at the adjacent margins between the 4th and 5th lumbar vertebrae and the intervertebral discs between them. The interoperative window was defined as the minimum distance between the abdominal aorta and the psoas major muscle.

TimoThy T. Davis et al. [10] dissected 20 fresh frozen cadaveric specimens to observe the L2-S1 interstitial window. The interbody window sizes were 18.60 mm and 25.5 mm at L2/3,19.25 mm and 27.05 mm at L3/4, 15.00 mm and 24.45 mm at L4/5, and 14.75 mm and 23.85 mm at L5/S1 at rest and during slight contraction of the psoas major muscle, respectively, while the commonly used interbody fusion was 18 mm, which allowed passage through the interbody window. This study confirms the feasibility of OLIF surgery through the natural interspace.

Jia Xi et al. [11] analyzed magnetic resonance images of 200 patients with degenerative lumbar spine disease and found that the L1/L2 interstitial window was 18.90 mm, L2/L3 was 15.50 mm, L3/L4 was 12.75 mm, and L4/L5 was 8.92 mm on the left side; on the right side, the L1/L2 interstitial window was 14.80 mm, L2/L3 was 5.50 mm, and In L1-L5, the left interstitial window was significantly larger than the right interstitial window; therefore, the left side was superior to the right side for OLIF surgery.

Julia Poh-Hwee Ng et al. [12] classified interstitial windows into four classes according to their size: class 0 without interstitial window, class 1 small interstitial window (≤1 cm), class 2 moderate interstitial window (1-2 cm), and class 3 large interstitial window (>2 cm). The interstitial window positions were classified as anterior oblique (AO), oblique (O), and lateral oblique (OL). The mean length of the interstitial window was 1.163 cm, with 10.5% of patients having a grade 0 interstitial window, 35.0% having a grade 1 interstitial window, 37.2% having a grade 2 interstitial window, and 17.4% having a grade 3 interstitial window. Of the patients with interstitial windows 1-3, 89.6% had oblique positions. This result suggests that 10.5% of the patients did not have a suitable OLIF approach, while in patients with surgical access conditions, the access angle was in the oblique position, i.e., 30°- 60°.

Lumbar segmental artery

Tianliang Wu et al. [13] reviewed 50 angiographic CT images in which the distance from the lumbar segmental artery to the upper and lower edges of the vertebral body (La, Lb) and the angle between the lumbar segmental artery and the anterior edge of the vertebral body as it enters the vertebral body were measured in the sagittal plane at the anterior 1/4 of the midline of the intervertebral disc. The lumbar segmental artery was divided into zones I-IV according to the Moro subdivision[14] and into types I-IV according to the degree of crossing the vertebral body, depending on the area where the lumbar segmental artery crosses the vertebral body. In zone I, the most common type of lumbar segmental artery is type IV at L1 and L2, type III at L3, and type II at L4 and L5; in zone II, the most common type of lumbar segmental artery is type III at L1-L4 and type II at L5; in zone III, the most common type of lumbar segmental artery is type III at L1-L4; in zone IV, the most common type of lumbar segmental artery is type IV at L3 -L5 is type IV. The authors concluded that the risk of injury to the lumbar segmental artery during OLIF is minimal when the fusion is placed in zones II and III, while caution is required when placed in zones IV at L3-L5. The fixation nail should be fixed at the superior margin of the inferior vertebral body of L1-L2 and L2-L3 and the inferior margin of the superior vertebral body of L3-L4 and L4-L5.

Psoas major muscle

Zhe Wang et al. [15] divided the axial surface of the intervertebral disc into six zones transversely using the Moro partition, divided zones I, II, III, IV, and zones A and P by the location of the anterior tangential line of the psoas major muscle, divided the axial surface of the disc into five zones longitudinally, measured the right tangential line of the great arteries, divided the area between the midline (through the center of the disc and the spinous process) and the left edge of the disc into zones a, b, and c, and divided The area to the right of the midline of the disc and the area of the left edge of the disc were defined as the R and L zones, respectively. It was found that the left psoas major muscle and abdominal aorta were in the Ib, IIb, Ic, Ab, and Ac regions in most patients. This suggests that OLIF surgery is feasible in the majority of people in the L2-L5 segment. In contrast, the AL region was seen only in L4/5, in 10 cases (6.0%) in men and 12 cases (9.0%) in women, for a total of 22 cases (7.3%). In these cases, the risk of large vessel injury was relatively high due to the narrow interoperative window.

Julia Poh-Hwee Ng et al. [12] further subdivided the anterior zone into four zones by a modified Moro partition, named AI-AIV, reflecting the mirror image of zones I-IV, with intervals calculated in quarters corresponding to the length of the IV disc in the original Moro classification. This modified Moro partition has good results for subtyping the variant psoas major muscle. The results showed that at the L4/5 level, 47.4% of patients were type AI, 30.7% were type I, while the least common was type IV, 0.2%, followed by type AIV (1.1%). In 19.4% of patients, the psoas major muscle was elevated (i.e., modified Moro subdivision type AII-AIV), and the authors concluded that this type was not suitable for OLIF surgery.

Masahiro Inoue et al. [16] extracted the cross-sectional area (CSA) of the psoas major muscle by a dedicated workstation, measured the CSA of the psoas major muscle before surgery, 1 week, 3 months, 6 months, and 12 months after surgery, and evaluated the ratio of the CSA of each access side of the psoas major muscle to the CSA of the contralateral side in each period, and the CSA ratios were 1.08 ± 0.21 before surgery, 1 week after surgery 1.25 ± 0.24, 3 months postoperatively 1.05 ± 0.08, 6 months postoperatively 1.02 ± 0.10, and 12 months postoperatively 1.05 ± 0.16, with 1 week postoperatively significantly higher than all other periods ($P<0.05$). This study suggests that the OLIF approach causes temporary damage or swelling of the psoas major muscle, but long-term damage to the muscle is not significant.

Lumbar sympathetic trunk

The lumbar plexus consists of the anterior branches of the 1st-3rd lumbar nerves and a portion of the anterior branch of the 4th lumbar nerve. The branches of the lumbar plexus run ventral to the psoas major muscle. At its lateral border, from top to bottom, are the inferior skeletal ventral nerve, the skeletal inguinal nerve, and the lateral femoral cutaneous and femoral nerves. The anterolateral side of the nerve is pierced by the genitofemoral nerve. The medial border of the nerve is pierced by the foraminal nerve, the paramedian foraminal nerve, and the superior root of the lumbar low trunk. The innervated psoas major muscle is mainly innervated by the anterior branches of the lumbar nerve (L1, L2, and part of L3).

The lumbar portion of each lumbar sympathetic trunk usually contains four interconnected ganglia, which travel within the extraperitoneal connective tissue anterior to the spine and along the medial border of the psoas major muscle. In the upper part, the lumbar sympathetic trunk continues posteriorly to the thoracic sympathetic trunk in the medial arcuate ligament [17]; in the lower part, it continues posteriorly to the pelvic sympathetic trunk via the common skeletal artery. On the right side, the lumbar sympathetic trunk is located posterior to the inferior vena cava, and on the left, it is posterior to the lateral aortic lymph nodes. The lumbar sympathetic trunk lies anterior to most of the lumbar vessels but may cross posterior to some lumbar veins. l1/L2 and sometimes L3 anterior branches emanate white communicating branches that communicate with the corresponding lumbar sympathetic ganglia. All lumbar ventral branches join four long gray-traffic branches of the lumbar sympathetic trunk at their origins. Their distribution is irregular, one ganglion may give off 2-3 anterior branches, one side of the lumbar anterior branch may receive branches from 2 ganglia, or gray branches from the sympathetic trunk between 2 ganglia [18]. The lumbar sympathetic trunk is vulnerable to damage during retroperitoneal ganglion dissection, and their damage can cause ejaculation, leading to retrograde ejaculation.

Hongli Wang et al. [19] performed magnetic resonance examinations on 44 healthy young adults to observe the relationship between the left lumbar sympathetic trunk and the abdominal aorta and lumbar major muscle. The distance from the left edge of the abdominal aorta to the left lumbar sympathetic trunk decreased significantly from the L2/3 segment to the L4/5 segment (11.14 ± 2.89, 9.36 ± 2.79, and 6.63 ± 2.94 mm). The distance from the anterior border of the left psoas major muscle to the left lumbar sympathetic trunk was not statistically significant between adjacent segments (2.96 ± 0.62, 2.83 ± 0.62, and 3.07 ± 0.86 mm). In the L2/3 segment, the left lumbar sympathetic trunk was positioned more posteriorly and laterally, whereas, in the L3/4 and L4/5 segments, the left LST was located anterolaterally. This result suggests that the left lumbar sympathetic trunk is located within the OLIF surgical approach from L2/3 to L4/5, which has some risk of injury during the procedure. At the L2/3 segment, the surgical gap was the largest and the left lumbar sympathetic trunk was located more posteriorly and laterally, suggesting that OLIF may be safer at the L2/3 segment. In the L4/5 segment, the incidence of left lumbar sympathetic trunk injury may be higher due to the narrow gap and anterior position of the left lumbar sympathetic trunk.

Genitofemoral nerve

The genitofemoral nerve originates from the anterior branch of L1/2, forms on the surface of the psoas major muscle passes through the psoas major muscle in an oblique anteriorly descending direction, and passes from the psoas major muscle along the abdominal surface of the medial margin at the level of the 3rd or 4th lumbar vertebra [14]. It descends beneath the peritoneum on the surface of the psoas major muscle, passes obliquely posterior to the ureter, and branches into the genital and femoral branches above the inguinal ligament. It also often branches shortly after its origin and penetrates the psoas major muscle separately [20]. Injuries like the skeletal inguinal nerve and the genital branch may be damaged during groin surgery, resulting in neuralgia [21]. To reduce the potential risk of nerve risk of injury, care should be taken when placing the dilated access retractor blade. The lumbar muscle retraction time needs to be limited, and care should be taken not to damage the lumbar fascia during intraoperative manipulation. The lumbar major retractor blade should be placed with care to ensure that it is sufficiently stable and that the duration of pulling is limited.

Ureter

The retroperitoneal segment of the ureter drops linearly at the level of the 2nd ~ 5th lumbar vertebra, and the Angle of inclination gradually increases from L2-3 to L5-S1. The ureter gradually shifts from the lateral margin of the psoas to the medial side during the descending process of the retroperitoneal space. The ureter is relatively safe when it is located at the lateral margin of the psoas, while it is more prone to injury when it is located at the anterior or medial side of the psoas. After the injury, there may be lumbago, abdominal pain, fever, hematuria, and other symptoms. Some patients have hidden symptoms that are not detected until several days after surgery.

Liang Xiao et al. [22] performed a retrospective analysis of 234 urographic-enhanced CT cases. The size of the angle between the ureter and the anterior border of the psoas major muscle was used to determine whether the ureter was within the surgical access. It was found that the angle of the ureter gradually increased from L2-L5, reflecting the gradual displacement of the ureter from the lateral edge of the psoas major muscle to the anteromedial side during the descent of the retroperitoneal space and with the approach of the ureter to the level of the coccyx, the ureter was displaced ventrally. The bilateral access range of OLIF gradually decreased from L2/3 to L4/5, and the left access was greater than the right at the same level. The risk of ureteral injury is high at the right L3/4 level and the bilateral L4/5 level. In particular, the right ureter located at the L4/5 level is most likely to be injured.

Voin et al. [23] found that 87.5% of ureters followed the path of 2.5cm behind the anterior margin of L2, 3.0cm behind the anterior margin of L3, 1.0cm behind the anterior margin of L4 and L5 through the fluoroscopy of the ureter of cadaver specimens. Generally speaking, the ureter passes laterally through the posterior 1/3 of the upper lumbar vertebrae, approaches the middle 1/3 laterally at the L3 vertebrae, reaches the front 1/3 laterally at the L4 and L5 vertebrae, and then descends into the pelvis.

Fujibayashi et al. [24] reported that 90.4% of the ureters were located in front of the psoas major muscle, close to the OLIF operation area. Although the ureter and peritoneal contents slip forward together in the lateral position, there is still insufficient ureter loosening, which may lead to the risk of injury, especially in emasculated patients. Thus, as the lumbar segment decreases, the safe operating area for OLIF decreases, and the possibility of ureteral injury increases, especially on the right side. Intraoperative evaluation should be performed through direct eye finger palpation to confirm that the ureter is not in the operating area and to ensure that the passage can be placed safely to avoid intraoperative ureter injury.

L5/S1

Compared with other segments, the anatomical structure of the OLIF operating window at L5-S1 segments is more complex and variable. Both the upper and left margins of the L5-S1 operating window are important blood vessels. Therefore, blood vessels are crucial to the feasibility of OLIF at L5-S1 segments. Molinares et al. [25] found that the common iliac vein confluent between the upper 1/3 of L4 and the lower 1/3 of L5 vertebra, and the lower the bifurcation of the vena cava, the less likely OLIF surgery was performed on the L5-S1 intervertebral disc. Only 69% of patients had surgical Windows, and the confluent common iliac vein could be a decisive factor in predicting the accessibility of the L5-S1 intervertebral disc. The L5-S1 OLIF is essentially an anterior lumbar interbody fusion (ALIF) performed in the lateral decubitus position. The procedure is performed across the left common iliac vein (LCIV), which is particularly important for protection. LCIV is the most common vascular lesion structure in ALIFs at the L5 to S1 segments because it is usually located medial to and occludes the L5 to S1 discs. Therefore, preoperative evaluation of vascular structure is necessary during OLIF surgery for L5-S1. CHUNG et al[26] classified LCIV into three types according to the ease of release: Type I (no need for release; LCIV is located beyond the left 2/3 of the L5-S1 disc), type II (easy release; LCIV is located within the left 2/3 of the L5-S1 disc; perivascular adipose tissue is present under the LCIV), and type III (potential difficulty in release; LCIV is located within the left 2/3 of the L5-S1 disc; Type III LCIV configuration has the highest probability of vascular injury. Therefore, preoperative vascular assessment of L5-S1 segment OLIF should include the location of LCIV and the presence of perivascular adipose tissue between LCIV and L5-S1 intervertebral disc. CHUNG et al. [27] also suggested that a lateral approach using the lateral side of the left iliac artery could be used as an alternative to OLIF surgery at the L5-S1 segment when there is a risk of vascular or plexus injury through the central approach to the L5-S1 intervertebral disc space. Berry et al. [28] suggested that L5-S1 segmental fusion through the left approach often required ligation of iliolumbar veins, segmental veins, median sacral vessels, and other structures to achieve full exposure of the operative area, which was much higher than other fusion segments. Zairi et al. [29] also suggested that iliac lumbar veins should be ligation first to safely release iliac vessels to reduce the risk of vascular injury in L5-S1 segments. Song et al. [30] compared the anatomy of the left and right blood vessels in the L5-S1 intervertebral disc space and found that the blood vessels in the left L5-S1 intervertebral disc space were 12.47mm from the median line, and the right side was 16.93mm, and the right side had many arteries with perivascular adipose tissue, so the risk of vascular injury was low. The L5 ~ S1 right approach can also be used as an alternate approach for OLIF surgery.

Position change

R. DeukmeDjiAn et al. [31] used magnetic resonance to scan the changes in the position of the aorta, inferior vena cava, iliac vessels, and kidneys in 10 adults when they were shifted from the supine to the left lateral and right lateral positions. In L1/2 and L2/3, the aorta and inferior vena cava were located away from the surgical access when the patient was in the lateral position. At L3/4, both the aorta in the left lateral position and the inferior vena cava in the right lateral position is slightly posterior, but the inferior vena cava tends to move more than the aorta, and the authors suggest that the right-sided approach may be safer in this segment. The right-sided approach at L4/5 also favors the left-sided approach because the right common iliac vein shifts anteriorly while the left-sided approach shifts posteriorly. The morphology of the psoas major muscle does not move measurably in the supine to the lateral position, but its morphology may flatten and compress. Aqib Zehri et al. [32] compared the change in the interoperative window in the supine, preoperative MRI axial, and intraoperative CT in the right lateral position and confirmed a statistically significant increase from the supine to the lateral position at all levels. Kaissar Farah et al. [33] used magnetic resonance to scan the area changes of the psoas major muscle in 10 healthy subjects in supine and left hip extension versus flexion positions, as well as interval window changes, and vasomotion. The results revealed that the mean surface area of the left psoas major muscle in the three positions ranged from 7.83-17.19 cm^2 ($p>0.05$). From L2/3 to L4/5, there was no significant difference in interval window and vasomotion when the left hip joint was changed from extension to flexion. When subjects were shifted from supine to right lateral position with the hip in extension, arteries were shifted to the right by 3.66-5.61 mm (L2/3, L3/4, L5/S1, $p<0.05$), and venous structures were shifted to the right by 0.92-4.96 mm (L2/3, $p<0.05$). When shifting from supine to right lateral position with hip flexion, the arterial structures shifted to the right 0.47-4.88 mm (L2/3 and L3/4, $p<0.05$) and the venous structures shifted to the right -0.94 - 4.13 mm (L2/3 and L3/4, $p<0.05$). Therefore, the authors concluded that extension and flexion of the hip joint do not affect the size of the interval window, but right lateral recumbency with hip extension reduces the psoas major muscle area and makes the procedure smoother.

Conclusion

In conclusion, the anatomical structure related to the surgical approach is the basis of surgical operation, and the formulation of various classification criteria based on the anatomical structure related to the surgical approach is conducive to preoperative evaluation and decision-making and becomes a beneficial tool during the operation. Complications associated with the anatomic approach tend to be high in the early stage of the new surgical technique, and gradually decrease with further study. Compared with ALIF and LLIF, the OLIF approach relies on natural space and is more acceptable to physicians and patients. The OLIF approach has a lower risk of damage to the anatomic structure associated with the approach while protecting the posterior ligament complex, paravertebral muscle, and osseous stable structure. However, it should be noted that perfect preoperative imaging examination and evaluation, familiarity with the anatomical structure of the approach, and good preoperative planning are the main measures to ensure the surgical effect and reduce complications. During the operation, the gentle and cautious operation is ensured to ensure that the operation is carried out under direct vision, and the surgeon should be able to judge and deal with serious complications in time, to maximize the advantages of the OLIF minimally invasive approach.

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