Imaging Anatomic Research of Oblique Lumbar Interbody Fusion in a Chinese Population Based on Magnetic Resonance

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■ OBJECTIVE: **To provide anatomic evidence of preoperative assessment of oblique lumbar interbody fusion (OLIF) for Chinese patients.**

■ METHODS: **From the hospital picture archiving and communication system, 400 lumbar magnetic resonance imaging studies of adults performed between November 2016 and January 2017 were selected. L2-3, L3-4, L4-5, and L5-S1 transverse and sagittal images were studied, and anatomic parameters associated with OLIF surgery, including bare window and psoas window, were measured and recorded. SPSS software was used for data summarization, sorting, and analysis to explore the significance of various anatomic parameters.**

■ RESULTS: **OLIF surgical corridors to the L2-S1 discs were found in most magnetic resonance imaging scans studied. The size of the psoas affects the difficulty of psoas muscle traction. It is relatively easy to perform OLIF surgery in older women. Most of the human iliac arteries were bifurcated and aggregated in front of the L4-5 intervertebral disc. The lower the aggregate level of the common iliac vein, the less likely it was to have the OLIF surgical corridor in the L5-S1 segment. The most frequently used lengths for a lumbar interbody cage for OLIF for Chinese patients are 50 mm and 55 mm.**

■ CONCLUSIONS: **OLIF can be a good choice for lumbar intervertebral fusion, including L5-S1 segment, in most Chinese patients. Older women are likely to have more scope of OLIF surgery. As a routine preoperative examination, lumbar magnetic resonance imaging is of great importance to OLIF surgery preoperative assessment.**

INTRODUCTION

Lumbar interbody fusion is a classical surgical method for the treatment of lumbar degenerative diseases. After years of clinical verification, its curative effect is generally considered satisfactory. In recent years, with the development of surgical techniques and instrumentation, many minimally invasive intervertebral fusion procedures have emerged, mainly including minimally invasive transforaminal lumbar interbody fusion, extreme lateral interbody fusion (XLIF), and oblique lumbar interbody fusion (OLIF).[1] OLIF was first reported by Silvestre et al. in 2012.[2] Currently it has become one of the most popular surgeries among spine surgeons in the world. The natural space between the abdominal aorta and the left psoas major is used to gain access to the intervertebral discs in OLIF. Compared with anterior lumbar interbody fusion, in OLIF, the large abdominal vessels do not need to be separated and pulled and the risk of vascular damage is greatly reduced. In addition, as the oblique approach does not go through the psoas major, complications such as lesion of the lumbar plexus or femoral nerve caused by XLIF are effectively avoided.[3] Because of the aforementioned advantages, more and more spine surgeons are trying to perform this surgery, and OLIF is a promising technique for lumbar interbody fusion.

The development of any new surgical technique is based on its local anatomic research. As OLIF is an emerging technology,

Key words
- Chinese
- Imaging anatomical research
- Interbody fusion
- Magnetic resonance
- OLIF
- Operative window
- Surgical corridors

Abbreviations and Acronyms
MRI: Magnetic resonance imaging
OLIF: Oblique lumber interbody fusion
XLIF: Extreme lateral interbody fusion

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systematic anatomic research, which is necessary to guide surgeons to further improve surgical skills is lacking. So far, literature recording the anatomy of OLIF has been sparse. In 2014, Davis et al.[4] studied the related anatomy of OLIF at L2-S1 with cadavers. In 2015, Molinares et al.[5] documented the oblique corridors of 100 American patients through magnetic resonance imaging (MRI) analysis. In 2016, Liu et al.[6] observed the applied physiologic anatomic parameters of OLIF operative windows through computed tomography angiography. In this study, we observed and recorded physiologic anatomic parameters of OLIF in 400 Chinese subjects through MRI and analyzed their clinical significance, thereby providing anatomic evidence for development of OLIF for Chinese patients.

MATERIALS AND METHODS

General Data

From November 2016 to January 2017, we selected imaging data from 400 adults who underwent 1.5T MRI of the lumbar spine. Of subjects, 59% were women and 41% were men. The average age was 50 years (range, 19—86 years). All subjects had clear axial and sagittal MRI scans. None of the subjects had lumbar anterior great vascular abnormalities or disorders, lumbar vertebra deformation, or a history of lumbar surgery or retroperitoneal surgery.

Methods

MRI scans were reviewed by the authors in the Centricity radiology information system/picture archiving and communication system customer edge program (General Electric Company, Fairfield, Connecticut, USA). T2-weighted MRI scans were analyzed in axial and sagittal planes. All anatomic parameters were measured 3 times at different points in time, and the averages were taken.

The L2-3, L3-4, and L4-5 intervertebral discs were first localized in the axial view. The anatomic parameters of L2-3, L3-4, and L4-5 (Figure 1) were as follows: the vascular window (the distance from the left boundary of the abdominal aorta or left iliac vessels to the median sagittal plane), the bare window (the left front of the intervertebral disc that is not covered by the abdominal aorta and left psoas major), the psoas major window (the left front of the intervertebral disc that is covered by the left psoas major), the width of the left psoas major, the thickness of the left psoas major on the middle frontal plane of the intervertebral space, and the transverse diameter.

The L5-S1 intervertebral disc images were different in the axial view. Owing to the abdominal aortic bifurcation and common iliac venous confluence in front of the L5-S1 level, the left psoas major did not cover the intervertebral discs, and there is no psoas major window at the L5-S1 level. The bare window (Figure 2) is the right boundary of the left iliac vessel to the median sagittal plane. Behind the bare window, the distance from the first vessel that crossed the midline below the aortic bifurcation (often the common left iliac vein) to the inferior endplate of L5 was measured vertically in the midsagittal plane, called the vertical bare window (Figure 3). The level of the aortic bifurcation and the common iliac venous confluence relative to vertebral body was observed with combined sagittal and axial images.

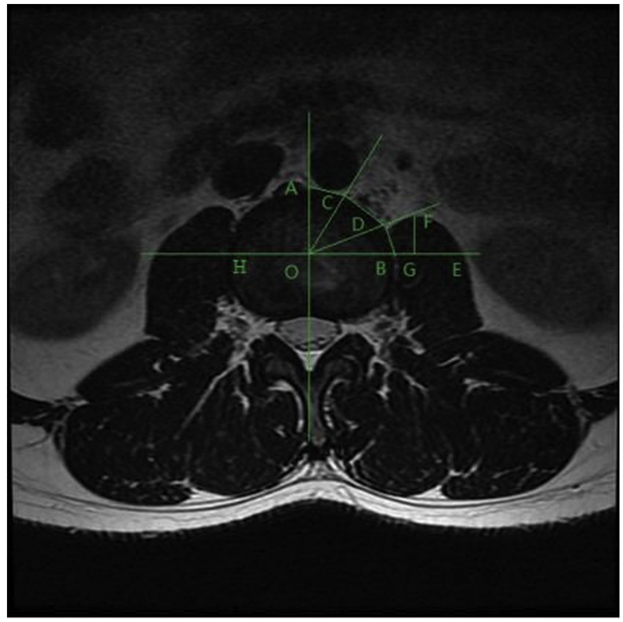

Figure 1. Transverse section of L2-3 level. O, approximate oval intervertebral space center; AC, vascular window; CD, bare window; BD, psoas major window; BE, left psoas major width; FG, psoas major thickness; BH, transverse diameter.

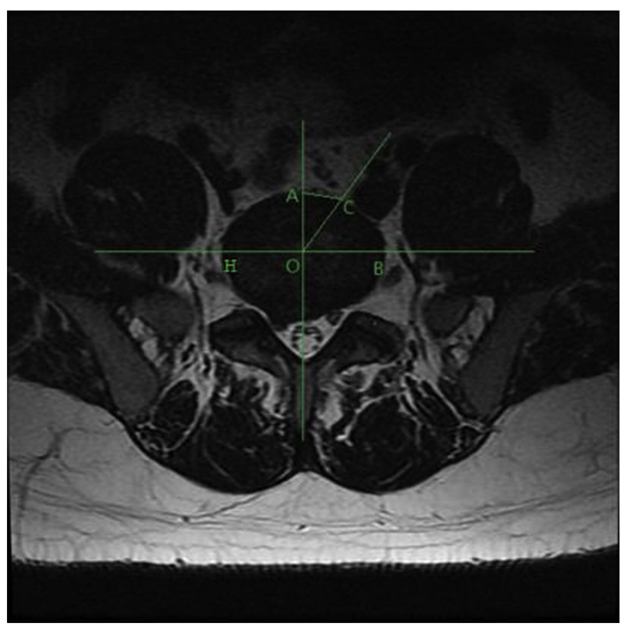

Figure 2. Transverse section of L5-S1 level. AC, bare window; BH, transverse diameter; O, approximate oval intervertebral space center.

Figure 3. Vertical bare window—the distance from the first vessel crossing midline to the inferior endplate of L5.

Table 1. Parameters of Operative Window of Each Level

Levels	Mean ± SD (mm)	Min (mm)	Max (mm)
L2-3			
Vascular window	11.06 ± 4.01	0	24.88
Bare window	14.26 ± 4.58	0	29.03
Psoas major window	10.43 ± 4.21	0	22.24
L3-4			
Vascular window	10.31 ± 3.64	0.76	22.67
Bare window	13.65 ± 4.55	0	28.44
Psoas major window	13.40 ± 4.23	0	25.25
L4-5			
Vascular window	13.98 ± 5.42	0	29.37
Bare window	10.08 ± 6.04	0	30.03
Psoas major window	13.90 ± 3.94	4.44	30.79
L5-S1			
Bare window	12.80 ± 6.25	0	31.08
Vertical bare window	10.60 ± 8.63	0	41.90

Min, minimum; Max, maximum.

Statistical Analysis

All the anatomic parameters are presented as mean ± SD. An unpaired t test was used to analyze the differences between levels and between sexes; $P < 0.05$ indicated a significant difference. One-way analysis of variance was used to analyze the differences between the left psoas major width and thickness of each age group; $P < 0.05$ again indicated a significant difference. χ^2 analysis was used to find a statistical difference in the level of the aortic bifurcation and iliocaval junction between men and women. IBM SPSS Version 20 software (IBM Corporation, Armonk, New York, USA) was employed for the statistical analysis.

RESULTS

Operative Window

The parameters of each level's operative windows (including vascular window, bare window, psoas major window, and vertical bare window) are listed in **Table 1**. The comparison of operative windows of L2-3, L3-4, and L4-5 levels is presented in **Table 2**. The comparison of operative windows between the sexes of each level is presented in **Table 3**.

The bare window is the area that can be operated on directly, so the size of the bare window is crucial to the operation. At L2-3 and L3-4, only 1 (0.25%) of the MRI scans did not have the bare window. At the L4-5 level, 29 (7.25%) of the MRI scans did not have the bare window. At the L5-S1 level, 36 (8%) of the MRI scans did not have the bare window. Of all 400 studied MRI scans, 79 (19.75%) did not have the vertical bare window.

The vascular window was largest at L4-5, followed by L3-4 and L2-3, and their sizes significantly differed ($P < 0.05$). The sizes at each level were compared between men and women to determine whether sex can influence the dimension of the vascular window. There were no significant differences between men and women at L2-3 and L3-4 ($P > 0.05$). At the L4-5 level, the vascular window sizes significantly differed ($P < 0.05$) and were found to be larger in women than in men.

The bare window was largest at L2-3, followed by L3-4, L5-S1, and L4-5. The unpaired t test was used to compare the differences between levels except L5-S1, as the L5-S1 level was particularly different from the other levels. There were no statistically significant differences between bare windows at L2-3 and L3-4 ($P > 0.05$). The bare window significantly differed ($P < 0.05$) between L2-3 and L4-5 and between L3-4 and L4-5. The unpaired t test was

Table 2. Operative Windows Measurement Difference Between Levels

Operative Window	Levels	*P* Value
Vascular window	L2-3 versus L3-4	0.006
	L2-3 versus L4-5	0.000
	L3-4 versus L4-5	0.000
Bare window	L2-3 versus L3-4	0.082
	L2-3 versus L4-5	0.000
	L3-4 versus L4-5	0.000
Psoas major window	L2-3 versus L3-4	0.000
	L2-3 versus L4-5	0.000
	L3-4 versus L4-5	0.107

Table 3. Comparison of Operative Window Between Sexes

	Mean ± SD (mm)		Min (mm)		Max (mm)		
Levels	Male	Female	Male	Female	Male	Female	*P* Value, Male versus Female
L2-3							
Vascular window	11.17 ± 3.99	10.98 ± 4.04	0	1.39	24.88	21.78	0.633
Bare window	13.40 ± 4.66	14.79 ± 4.55	0	3.96	28.16	29.03	0.003
Psoas major window	12.81 ± 3.50	8.78 ± 3.86	2.57	0	22.24	21.42	0.000
L3-4							
Vascular window	9.99 ± 3.54	10.52 ± 3.71	0.76	1.12	22.54	22.67	0.153
Bare window	12.51 ± 4.41	14.45 ± 4.50	3.78	0	25.72	28.44	0.000
Psoas major window	16.38 ± 3.12	11.32 ± 3.63	8.28	0	25.25	20.71	0.000
L4-5							
Vascular window	12.88 ± 5.70	14.74 ± 5.11	0	1.09	29.37	26.80	0.001
Bare window	9.74 ± 5.89	10.31 ± 6.15	0	0	24.82	30.03	0.349
Psoas major window	16.73 ± 2.86	11.88 ± 3.44	8.45	4.44	26.27	30.79	0.000
L5-S1							
Bare window	11.14 ± 6.30	13.95 ± 5.97	0	0	31.08	25.4	0.000
Vertical bare window	9.60 ± 8.97	11.30 ± 7.99	0	0	41.6	41.9	0.048

Min, minimum; Max, maximum.

also used to compare the differences between sexes. The bare window at the L4-5 discs were found to be slightly larger in women than in men ($P > 0.05$). In contrast, larger bare windows at L2-3 and L3-4 levels were observed in women ($P < 0.05$). In addition, the vertical bare window significantly differed ($P < 0.05$), also more in women than in men.

The psoas major window was largest at L4-5 and smallest at L2-3. There were no statistically significant differences between L3-4 and L4-5 levels. The psoas major window significantly differed ($P<0.05$) between other levels. There were significant differences between men and women at all levels ($P < 0.05$).

Psoas Major Width and Thickness

The width and thickness of the psoas major roughly indicate the difficulty in expanding the scope of OLIF surgery by pulling or stripping the left psoas major during surgery (Table 4). The width and thickness of the psoas major were greater in men than in women at each level, and the differences were statistically significant ($P < 0.05$), indicating that the psoas major in men is generally wider and thicker than the psoas major in females. The differences in each level were statistically significant (L4-5 > L3-4 > L2-3; $P < 0.05$), indicating that the lower the psoas major is, the wider and thicker it is, and thus the more difficult it is to pull the psoas major muscle during surgery.

Different ages were grouped to understand the effect on surgery of degeneration of the psoas major due to aging (Table 5). With increasing age, the width of the psoas major at each level becomes smaller and smaller, but the thickness of the psoas major does not change with age. One-way analysis of variance was used to analyze the differences among all age groups, and $P < 0.05$ indicated a significant difference.

Aortic Bifurcation and Iliocaval Junction

The abdominal aortic bifurcation and common iliac venous confluence are in front of the lower lumbar vertebra. The aortic bifurcation was observed between the L3-4 disc and the middle third of the L5 vertebral body. The confluence of common iliac veins was found between the superior third of the L4 vertebral body and the inferior third of the L5 vertebral body (Table 6). χ^2 analysis was used to compare the level of the aortic bifurcation and iliocaval junction in relation to the sex of the subjects. There were no statistically significant differences in the aortic bifurcation between the sexes ($P = 1.090$). However, the iliocaval junction significantly differed between men and women ($P = 0.022$).

Previous studies have shown that the lower the confluence of common iliac veins, the less probable it was that access to the L5-S1 disc was found. To confirm this, the number of subjects without surgical area (L5-S1 bare window or vertical bare window equal to zero) in each iliocaval junction group and their percentage are shown in Table 7. Most of the confluence of common iliac veins was observed at the L4-5 disc level. In 1 of 57 cases (1.75%) where the iliocaval junction was identified at the L4 level, no access to the L5-S1 disc was observed. In 5 of 126 cases (3.97%) where the iliocaval junction was identified at the L4-5 disc, no access to the L5-S1 disc was observed. In 21 of 65 cases (32.31%) where the iliocaval junction was found at the middle third of the

Table 4. Psoas Major Width and Thickness

	L2-3		L3-4		L4-5	
	Width	**Thickness**	**Width**	**Thickness**	**Width**	**Thickness**
Male	17.02 ± 4.95	13.69 ± 3.75	27.03 ± 6.59	17.89 ± 4.10	37.38 ± 6.01	24.52 ± 6.18
Female	10.83 ± 4.18	8.86 ± 3.85	18.42 ± 5.73	11.61 ± 3.99	31.09 ± 6.23	16.87 ± 5.76
P value	0.000	0.000	0.000	0.000	0.000	0.000
Male + female	13.37 ± 5.44	10.84 ± 4.49	21.95 ± 7.42	14.18 ± 5.08	33.67 ± 6.87	20.00 ± 7.02

All values are mean ± SD (mm).
Psoas major width: L2-3 versus L3-4, $P = 0.000$; L3-4 versus L4-5, $P = 0.000$; L2-3 versus L4-5, $P = 0.000$.
Psoas major thickness: L2-3 versus L3-4, $P = 0.000$; L3-4 versus L4-5, $P = 0.000$; L2-3 versus L4-5, $P = 0.000$.

L5 vertebral body, no access to the L5-S1 disc was found. In addition, in 56 of 70 cases (80%) where the iliocaval junction was identified at the inferior third of the L5, no access to the L5-S1 disc was observed. Interestingly, oblique access to the L5-S1 disc was found in no case where the iliocaval junction was identified in the superior third of the L5. On the whole, the level of confluence of the common iliac veins is likely to be a determining factor of accessibility to the L5-S1 disc.

Transverse Diameter

The transverse diameter was measured to estimate an applicable length for a lumbar interbody cage of OLIF for Chinese patients (Table 8). According to the result, for the OLIF cage, the most used lengths for men were 50 mm in L2-3 and 55 mm in L3-4, L4-5, and L5-S1; the most used lengths for women were 50 mm in L2-3, L3-4, and L5-S1 and 55 mm in L4-5. There were significant differences between men and women at all levels ($P < 0.05$).

DISCUSSION

Lumbar intervertebral fusion is a classical treatment for a range of spinal diseases, including degenerative pathologies, infection, trauma, and tumor.[1] Many approaches have been described for access to the intervertebral discs. In the early years, traditional open techniques, mainly including posterior lumbar interbody fusion, transforaminal lumbar interbody fusion, and anterior lumbar interbody fusion, were widely used and considered effective. With the development of surgical technique and instrumentation, many minimally invasive intervertebral fusion procedures have emerged, including minimally invasive posterior lumbar interbody fusion, minimally invasive transforaminal

Table 5. Psoas Major Width and Thickness of Each Age Group

	Width			Thickness		
Age Group (years) (*n*)	**L2-3**	**L3-4**	**L4-5**	**L2-3**	**L3-4**	**L4-5**
<40 (90)	15.81 ± 5.91	24.45 ± 8.12	35.90 ± 6.97	11.53 ± 4.29	14.68 ± 5.43	19.61 ± 6.67
40—49 (89)	14.51 ± 6.03	23.62 ± 7.67	34.96 ± 6.99	12.01 ± 4.99	15.59 ± 5.24	21.18 ± 7.26
50—59 (106)	13.10 ± 4.45	21.35 ± 6.75	34.09 ± 5.57	9.96 ± 3.79	13.55 ± 4.42	19.51 ± 6.98
60—69 (90)	11.36 ± 4.09	19.84 ± 6.08	30.97 ± 6.96	10.40 ± 4.42	13.88 ± 5.09	20.15 ± 7.25
>70 (25)	8.97 ± 4.13	17.14 ± 6.48	29.02 ± 5.87	9.56 ± 5.24	11.16 ± 4.15	18.80 ± 6.69

All values are mean ± SD (mm).
Difference of psoas major width at L2-3, 40 versus 40—49, 40—49 versus 50—59, 60—69 versus >70: $P > 0.05$; 40 versus 50—59, <40 versus 60—69, <40 versus >70, 40—49 versus 60—69, 40—49 versus >70, 50—59 versus 60—69, 50—59 versus >70: $P < 0.05$.
Difference of psoas major width at L3-4, 40 versus 40—49, 40—49 versus 50—59, 50—59 versus 60—69, 50—59 versus >70, 60—69 versus >70: $P > 0.05$; 40 versus 50—59, <40 versus 60—69, <40 versus >70, 40—49 versus 60—69, 40—49 versus >70: $P < 0.05$.
Difference of psoas major width at L4-5, 40 versus 40—49, <40 versus 50—59, 40—49 versus 50—59, 60—69 versus >70: $P > 0.05$; 40 versus 60—69, <40 versus >70, 40—49 versus 60—69, 40—49 versus >70, 50—59 versus 60—69, 50—59 versus >70: $P < 0.05$.
Difference of psoas major thickness at L2-3, 40 versus 40—49, <40 versus 50—59, <40 versus 60—69, <40 versus >70, 40—49 versus 60—69, 40—49 versus >70, 50—59 versus 60—69, 50—59 versus >70, 60—69 versus >70: $P > 0.05$; 40—49 versus 50—59: $P < 0.05$.
Difference of psoas major thickness at L3-4, 40 versus 40—49, <40 versus 50—59, <40 versus 60—69, 40—49 versus 60—69, 50—59 versus 60—69, 50—59 versus >70, 60—69 versus >70: $P > 0.05$; 40 versus >70, 40—49 versus 50—59, 40—49 versus >70: $P < 0.05$.
Difference of psoas major thickness at L4-5, 40 versus 40—49, <40 versus 50—59, <40 versus 60—69, <40 versus >70, 40—49 versus 50—59, 40—49 versus 60—69, 40—49 versus >70, 50—59 versus 60—69, 50—59 versus >70, 60—69 versus >70: $P > 0.05$.

Table 6. Aortic Bifurcation and Iliocaval Junction

Levels	Aortic Bifurcation, Number (%)		Confluence of Common Iliac Veins, Number (%)	
	Male	Female	Male	Female
L3-4 disc	9 (5.49)	10 (4.24)	0 (0)	0 (0)
L4 vertebral body				
Superior third	12 (7.32)	20 (8.47)	0 (0)	1 (0.42)
Middle third	28 (17.07)	46 (19.49)	4 (2.44)	5 (2.12)
Inferior third	42 (25.61)	84 (35.59)	17 (10.37)	30 (12.71)
L4-5 disc	61 (37.20)	64 (27.12)	45 (27.44)	81 (34.32)
L5 vertebral body				
Superior third	10 (6.10)	8 (3.39)	26 (15.85)	56 (23.73)
Middle third	2 (1.22)	4 (1.69)	37 (22.56)	28 (11.86)
Inferior third	0 (0)	0 (0)	35 (21.34)	35 (14.83)
Total	164 (100.01)*	236 (99.99)*	164 (100)	236 (99.99)*

*Values do not add to 100% owing to rounding.

lumbar interbody fusion, XLIF, and OLIF. Minimally invasive surgical approaches have become a safe alternative to traditional open techniques for many surgeons.

The development of minimally invasive surgery technology is mainly aimed at reducing operative times and achieving faster recovery with reduced operative complications. In 2006, Ozgur et al.[7] first described XLIF, and since then XLIF has been preferred by many surgeons due to ease of access, shorter operative time, larger cage placement, decreased tissue trauma, and minimal blood loss.[8] A working channel was used through the psoas major during XLIF; however, because the psoas major contains important nerves, mainly including the lumbar plexus, complications such as femoral nerve injury often occur. Monitoring may be required to decrease neural injury but is complicated.[9] To solve this problem, a new technique named OLIF has been developed in recent years.

The lumbar oblique approach was described by Mayer in 1977.[10] In 2012, Silvestre et al.[2] first reported OLIF. During the surgery,

Table 7. Access to L5-S1 Related to Level of the Iliocaval Junction

Iliocaval Junction Level	Number of Subjects	Number of Subjects with No Access to L5-S1 (%)
L4 vertebral body	57	1 (1.75)
L4-5 disc	126	5 (3.97)
L5 superior third	82	0 (0)
L5 middle third	65	21 (32.31)
L5 inferior third	70	56 (80)
Total	400	83 (20.75)

Table 8. Transverse Diameter of Each Level

Levels	Transverse Diameter, Mean ± SD (mm)		*P* Value, Male versus Female
	Male	Female	
L2-3	54.46 ± 4.71	50.13 ± 4.56	0.000
L3-4	57.15 ± 4.87	53.80 ± 4.78	0.000
L4-5	58.86 ± 4.76	55.37 ± 4.92	0.000
L5-S1	57.78 ± 6.12	54.20 ± 5.58	0.000

the patient was put in the right lateral decubitus position. A left abdominal oblique incision was selected, and the surgeon dissected through the muscle fibers of the obliquus externus abdominis, obliquus internus abdominis, and transversus abdominis into the extraperitoneal space. Blunt dissection was directed toward the place between the left psoas major and abdominal aorta, in which the working channel was placed through which a lumbar discectomy and interbody fusion were performed.[11,12] Because the natural space between the abdominal aorta and the left psoas major was used to gain access to the intervertebral discs, OLIF reduced the risk of abdominal vascular damage related to anterior lumbar interbody fusion. Meanwhile, complications, such as lesion of the lumbar plexus caused by XLIF, were effectively avoided because OLIF did not go through the psoas major.[3] In view of this, OLIF is likely to be a promising technique for lumbar interbody fusion. Currently OLIF is very popular outside of China, and surgeons in China have carried out the operation successively.

The development of any new surgical technique is based on its local anatomic research. Systematic anatomic research of OLIF is necessary to guide surgeons to further improve surgical skills. In 2014, Davis et al.[4] studied the related anatomy of OLIF at L2-S1 with 20 cadavers, measuring the oblique corridors with and without psoas retraction. In 2015, Molinares et al.[5] documented the oblique corridors of 100 American patients through MRI analysis. In 2016, Liu et al.[6] observed the applied physiologic anatomic parameters of OLIF operative windows, including vascular window, bare window, and psoas major window through computed tomography angiography. Liu et al.[13] suggested that anatomic measurements made in vivo are closer to the human surgical state and are more credible. Therefore, in this study, we observed and recorded physiologic anatomic parameters of OLIF in 400 Chinese subjects through MRI and analyzed their clinical significance, thereby providing anatomic evidence for Chinese OLIF development.

We followed the concept of OLIF operative window proposed by Liu et al.[6] The vascular window is the left front intervertebral disc area covered by the abdominal aorta (L4-5 level is usually the left common iliac artery), which is a surgically restricted area. The bare window is an exposed area where surgery can be performed directly. In our study, only 1 person in each segment of L2-3 and L3-4 had no bare window. At the L4-5 level, because of the abdominal aorta bifurcation, the scope of the vascular window becomes larger, and the bare window becomes smaller, but only

7.25% of the subjects did not have the bare window. Even if the bare window is not detected, there is still the possibility of OLIF surgery due to the existence of the psoas major window. The psoas major window indicates the scope of the left psoas muscle that needs to be stripped during surgery to increase the surgical area. Therefore, the actual operating window is the bare window plus the psoas major window. Davis et al.[4] believed that the retraction of the left psoas major could significantly increase the range of operation, increasing by 59.60% at L2-3, 43.96% at L3-4, and 58.97% at L4-5. The larger the actual operating window consisting of bare window and psoas major window is, the easier the exposure of the surgical field, indirect decompression of the canal, and intervertebral fusion will be. Compared with XLIF, OLIF does not need to split the psoas major; only the left psoas major is pulled backward through the fingers and the dilated catheter. However, significant stripping of the psoas major may stimulate the lumbar plexus. In fact, nerve injury is still one of the main complications of OLIF surgery. Joseph et al.[14] reported that the incidence of OLIF nerve injury was 1.2% (2 of 155), whereas Lykissas et al.[15] reported that the rate of XLIF nerve injury was 31.9% (145 of 454).

The size of the left psoas major may affect the difficulty of pulling the psoas major during surgery. The width and thickness of the psoas major probably indicate the difficulty of the psoas retraction. Our results showed that the width and thickness of the psoas major were L4-5 > L3-4 > L2-3. This finding is the same as the research results of Liu et al.[6] and is consistent with the physiologic anatomy of the human body, as the lower the psoas muscle, the wider and thicker it is. In the comparison of sex differences, we found that the psoas major of men is wider and thicker than the psoas major of women. In addition, it was found that the older the age group, the smaller the psoas major width was, which may be caused by atrophy of the psoas, but there was no regular change in the thickness of the psoas major. In general, we deem that older women tend to have a weaker psoas major and are more likely to have more scope of operation through traction.

The OLIF operation at L5-S1 level is different from other levels, in that the psoas major does not obstruct the intervertebral disc. Owing to the abdominal aortic bifurcation and common iliac venous confluence in front of the L5-S1 level, the operating window is located on the inner side of the vascular structure, and to some extent it is similar to the standard anterior lumbar fusion approach. We reckon that both the bare window and the vertical bare window affect the surgical range of L5-S1. In the study by Molinares et al.,[5] the intervertebral disc of L5-S1 could not be accessed in 31% of the population owing to the blockage of abdominal blood vessels. In our study, the L5-S1 disc could not be accessed in 20.75% of the subjects owing to the obstruction of vascular structure (bare window or vertical bare window equal to zero). In some subjects, the bare window and vertical bare window were greater than 0, but were still small, so actually the L5-S1 disc should not be able to be accessed in more patients. Therefore, during OLIF at L5-S1, caution is warranted to avoid iliac arteriovenous injury. Of the 179 cases of OLIF surgery reported by Silvestre et al.,[2] 3 (1.8%) developed complications of iliac vessels, and 1 case of OLIF surgery at the L5-S1 level was not completed, and OLIF was replaced with other operations. A vascular block slice may help protect the iliac blood vessels.[12] Molinares et al.[5] suggested that the confluence of common iliac veins was closely related to access to the L5-S1 disc—the lower the confluence, the less probable it was that anterior access to the L5-S1 disc was found. Our research yielded a similar result. In our study, most of the confluences of common iliac veins were observed at the L4-5 disc level. Capellades et al.[16] reported that the confluence of common iliac veins was found between the lower third of L4 and the superior third of L5 in 59.4% of 124 subjects. As the common iliac artery is higher than the common iliac vein in most people, the confluence of common iliac veins is likely to be a determining factor to accessibility to the L5-S1 disc. Chung et al.[17] evaluated the influence of the morphologic characteristics of the left common iliac vein on risk of mobilization at the L5-S1 disc. The left common iliac vein was categorized into three types according to the difficulty of mobilization, and cases of left common iliac vein with no perivascular adipose tissue under the vein (type III) showed a high rate of vascular injury. In short, the anatomy of OLIF at L5-S1 is more complex and variable than at other segments, which needs further study.

At the present time, only a few types of cage can be used in OLIF surgery, and most of them are imported polyetheretherketone cages. To estimate an applicable length for a lumbar interbody cage of OLIF for Chinese patients, we measured the transverse diameter, which defined as the maximal width of the intervertebral disc, and the most used lengths were 50 mm and 55 mm. The size of the OLIF cage is influenced by many factors, however, and a simple anatomic parameter may not be clinically relevant.

Existing studies have shown that OLIF has good clinical efficacy, short operative time, less blood loss, rapid recovery, and high fusion rate.[18-21] Our imaging anatomic study provides anatomic evidence for clinical development of OLIF, especially in the Chinese population. In our study, measurements of the size of the operative window were similar to the measurements obtained by Davis et al.[4] in their cadaveric study, but slightly reduced, possibly due to protein coagulation and tissue shrinkage in the formalin. In addition, the general body size of Chinese people is smaller than the body size of American people.

The present research has limitations. First, the measurements of each anatomic parameter may have errors. Additionally, L1-2 segments were not included in the study, mainly because most of the lumbar MRI scans performed in our hospital did not include the L1-2 axial planes. L1-2 OLIF should take into account the renal blood vessels located in the front of the lumbar spine, which is also one of the difficulties of OLIF surgery.[6] Fujibayashi et al.[22] found that 90.4% of ureteral anatomy was close to the OLIF operative corridor, so it is necessary to evaluate the anatomic position of the ureter before OLIF surgery. Finally, the results of imaging anatomic measurement need to be combined with clinical practice to further verify the accuracy of conclusions, which is also our further research objective.

CONCLUSIONS

OLIF can be a good choice for lumbar intervertebral fusion, including L5-S1 segment, in most Chinese patients. Older women are likely to have more scope of OLIF surgery. As a routine preoperative examination, lumbar MRI is of great importance in preoperative assessment for OLIF surgery.

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