Original Article

Vascular injury risk stratification for lateral lumbar interbody fusion (LLIF) at L4–L5: a morphometric study using magnetic resonance imaging

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Background: Proper vascular injury risk stratification (VIRS) methods for L4–L5 lateral lumbar interbody fusion (LLIF) surgery have not been well-described. The objective of this study was to propose a novel VIRS method for L4–L5 LLIF surgery via the transpsoas approach.

Methods: Axial magnetic resonance imaging (MRI) of adult patients were obtained and analyzed. The VIRS scores were assessed using anterior disc line to posterior vessel wall distance, the disc vessel angle (DVA), and the disc edge to vessel distance at the level of L4–L5 disc space.

Results: Ninety-one consecutive adult patients were included in the study. The right common iliac vein (CIV) had a high risk of injury with both right- and left-sided approaches. The left CIV had a moderate risk with a left-sided approach when the iliocaval confluence was above the L4–L5 disc space but had a high risk when the confluence was at the L4–L5 disc space. The left CIV had a high risk with a right-sided approach when the confluence was above the L4–L5 disc space but had a moderate risk when the confluence was at the L4–L5 disc space. The inferior vena cava (IVC) had a high risk with both right- and left-sided approaches. The aorta had a moderate risk regardless of the right or left-sided approaches. The left common iliac artery (CIA) had a moderate risk with a right-sided approach and a low risk with a left-sided approach. The right CIA had a low risk with both right- and left-sided approaches.

Conclusions: There are significant vascular anatomic variations at the L4–L5 disc level and a proper VIRS can be performed utilizing a combination of anterior disc line to posterior vessel wall distance, DVA, and disc edge to vessel distance, on the axial MRI.

Keywords: Transpsoas; lumbar fusion; feasibility; anatomic variation; lateral lumbar interbody fusion (LLIF)

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Introduction

Lateral lumbar interbody fusion (LLIF) surgery via the transpsoas approach has become a popular less invasive technique in spine surgery, offering anterior access to the vertebral column while theoretically avoiding the need for significant mobilization of the great vessels or lumbar plexus as is often required in other approaches (1). Over the past decade, its application has expanded to include a variety of pathologies including treatment of spondylolisthesis with stenosis and correction of coronal and sagittal plane deformity in both primary and revision settings (2-10). LLIF purports several advantages over traditional open approaches to the anterior spine including the ability to use smaller incisions, reduced complication rates, decreased operative times, decreased blood loss, diminished postoperative pain, shorter hospital stays, lower infection rates, and improvements in fusion rates (11-14). However, lateral access spine surgery carries inherent risk to neurovascular structures, most notably to the lumbar plexus, which is encountered primarily within the psoas muscle (15-17). Clinical impairment related to injury of these nerves has spurred multiple anatomic studies to identify the safety limitations of this approach with multiple cadaveric and imaging studies identifying the L4–L5 level as the most at risk (18-20).

Vascular injury to the great vessels is another potentially devastating complication of LLIF as these structures are intimately associated with the vertebral column, particularly at the L4–L5 level (21). Assina *et al.* reported a fatal case involving extensive lacerations to the inferior vena cava (IVC) and both common iliac veins (CIVs) related to anterior longitudinal ligament (ALL) retractor migration during an L4–L5 LLIF from a right-sided approach (22). Buric *et al.* described a right CIV injury that occurred during Cobb elevator dissection of the L4–L5 disc from the L4 inferior end plate during a right-sided LLIF approach, while Mousafeiris *et al.* reported an aortic laceration and right common iliac artery (CIA) injury during the cage placement at L4–L5 from a left-sided approach (23,24). Kueper *et al.* reported one case of an abdominal aorta injury during a L3–L5 LLIF (25). A prior study has shown that the iliocaval confluence occurs at or near the L4–L5 level (26). Nevertheless, the risk of injury to the iliac veins and IVC as it relates to the level of the iliocaval confluence has not previously been studied for LLIF. Previous studies have described specific risk stratification methods for vascular injury at L4–L5 by utilizing dorsal tangential lines of the major vessels within the disc space. However, these studies describe the risk of injury during the direct approach and do not describe the risk of injury to contralateral vessels during disc preparation (27-29). For instance, instruments used for disc preparation are commonly passed through the contralateral disc edge to assure contralateral annulus release and a pituitary rongeur is often utilized to complete the discectomy with limited direct visualization of the contralateral vessels (30). Thus, the location of the contralateral vessels in reference to the anterior disc line is important for preventing injury during disc preparation. Anterior angulation of the disc preparation instrumentation or pituitary rongeur increases the likelihood of contralateral vascular injury during disc preparation (*Figure 1*). Moreover, the distance between the great vessels and the disc edge provides an important surgical plane that allows for a margin of safety during LLIF surgery (31). This plane has been studied to determine the safety of performing an ALL release during anterior column realignment (ACR) surgery and has been shown to be the narrowest at the L4–L5 level (30). The aims of this study were to analyze normal variations of the iliocaval confluence with respect to the L4–L5 disc level and to propose a novel vascular injury risk stratification (VIRS) method for L4–L5 LLIF surgery that uses a combination of anterior disc line to posterior vessel wall distance, disc vessel angle (DVA) and disc edge to vessel distance at the L4–L5 disc space. We present this article in accordance with

Highlight box

Key findings

- Significant vascular anatomic variations exist at the L4–L5 disc level.
- Proper vascular injury risk stratification (VIRS) can be performed with a combination of anterior disc line to posterior vessel wall distance, disc vessel angle (DVA), and disc edge to vessel distance, on the axial magnetic resonance imaging (MRI).

What is known and what is new?

- Vascular injury is a potentially devastating complication of LLIF particularly at the L4–L5 level.
- Proper VIRS can be performed utilizing a combination of anterior disc line to posterior vessel wall distance, DVA, and disc edge to vessel distance, on the axial MRI.

What is the implication, and what should change now?

- Proper VIRS can be performed utilizing a combination of anterior disc line to posterior vessel wall distance, DVA, and disc edge to vessel distance, on the axial MRI.
- This stratification should be completed prior to performing an L4–L5 LLIF.

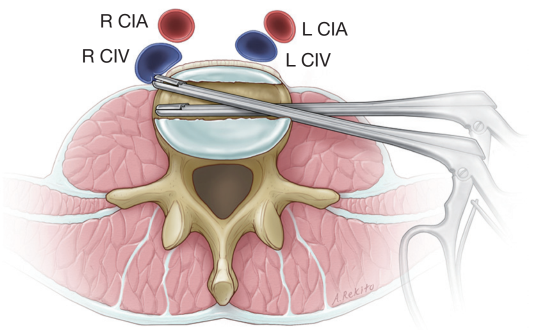

Figure 1 Illustrative example that demonstrates the risk for injury to the contralateral vessels during disc preparation. Illustration by Andy Rekito. R, right; L, left; CIV, common iliac vein; CIA, common iliac artery.

the STROBE reporting checklist (available at https://jss.amegroups.com/article/view/10.21037/jss-23-94/rc).

Methods

Patient selection

This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). An institutional review board (IRB) approved retrospective observational imaging study was performed (Institution: UT Health; Approval No. HSC-MS-12-0370). Individual consent for this retrospective analysis was waived. Lumbar spine magnetic resonance imaging (MRI) studies (1.5 Tesla) obtained in a supine position from consecutive adult patients at UT Health between 18 and 80 years of age dated from September 2007 to January 2012 were analyzed. Each series, consisting of axial, sagittal, and coronal T1-weighted, T2-weighted, and fat-saturated T2-weighted sequences, was evaluated with particular attention to the L4–L5 disc level. Demographic data including age, gender, ethnicity, height, and weight was reviewed as well for each patient. Exclusion criteria included prior lumbar spine, great vessel, or retroperitoneal surgery, any burst or compression fracture with resultant 50% or greater loss of height involving L3 to S1, infectious process, scoliosis, lumbar spondylosis or spondylolisthesis involving the L4–L5 level, or incomplete imaging.

Data collection

Each imaging study was obtained by a senior orthopaedic surgery resident using the measurement tools embedded in the picture archiving and communication system (PACS) (Centricity Enterprise Web, version 3.0; GE Medical Systems, Barrington, IL, USA). The anteroposterior and lateral dimensions of each L4–L5 disc space were measured and recorded. Venous and arterial great vessels were stratified into three groups based upon the location of the iliocaval confluence and the aortic bifurcation, respectively-either superior to, at the level of, or inferior to the L4–L5 disc space. The theoretical risk inherent to each of the great vessels (the left and right common iliac arteries and veins, the aorta, and the IVC) was determined based upon their locations relative to the L4–L5 disc. This was derived from axial MRI measurements, including anterior disc line to posterior vessel wall distance, DVA, and disc edge to vessel distance (*Figure 2*). The DVA was measured from both the right and the left disc edges to account for the difference in risks related to right versus left-sided approaches.

As individual anatomic variation can be widespread, each risk category was then assigned high (2 points), moderate (1 point), or low (0 points) risk. The sum of all three categories could then be used to determine the overall risk of injury to a given vessel using a right or a left-sided approach. A total of >4 points was deemed high risk, while 3–4 points was moderate, and <3 points was considered low risk (*Table 1*).

Regarding the anterior disc line to posterior vessel wall distance, vessels located more posteriorly relative to the anterior disc line were considered higher risk for injury given the line of dissection. Distances >5 mm posteriorly were considered high risk, whereas 0–5 mm posteriorly was assigned moderate risk, and vessels anterior to the anterior disc line (<0 mm posteriorly) were considered low risk.

Regarding the DVA, values between 0°–30° were considered high risk due to the risks for vessel injury associated with disc preparation using pituitary rongeurs, elevators and osteotomes. Angles between >30°–60° were considered moderate risk, and angles between greater than 60° were considered low risk.

Lastly, regarding the disc edge to vessel distance, vessels located closer to the nearest disc edge were considered higher risk for injury. Values <1 mm were considered high risk, 1–2.5 mm were considered moderate risk, and >2.5 mm were considered low risk.

Statistical analysis

Statistical analysis was performed using SPSS version 2.0 (Version 25.0; SPSS, Inc., Chicago, IL, USA). Student's

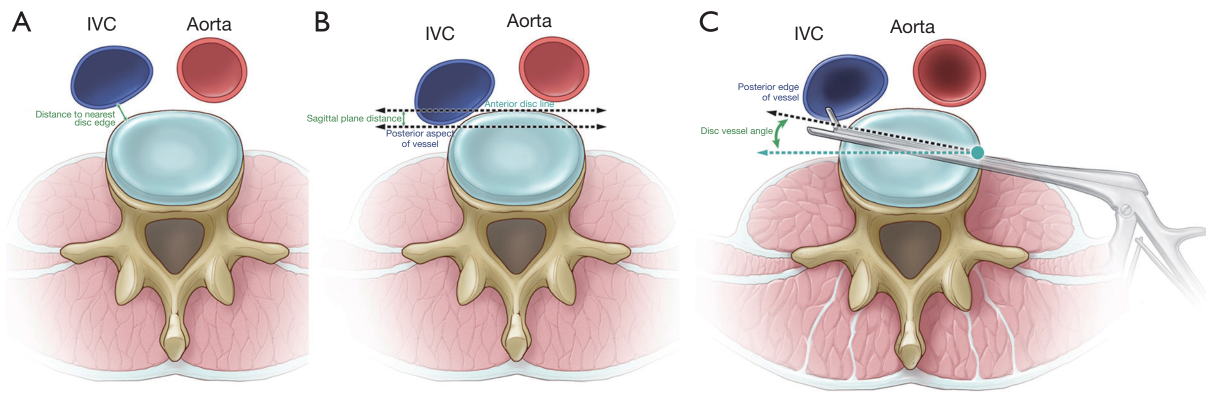

Figure 2 Illustrative examples at the level of the L4–L5 disc of the (A) disc edge to vessel distance, (B) anterior disc line to vessel distance, and (C) disc vessel angle for determining injury risk to the IVC from a left-sided approach. Illustration by Andy Rekito. IVC, inferior vena cava.

Table 1 Vascular injury risk stratification for lateral lumbar interbody fusion at L4–L5

Risk category	Point value
Anterior disc line to posterior vessel wall distance	
>5.0 mm posterior	2
0.0–5.0 mm posterior	1
<0.0 mm posterior (anterior vessels)	0
Disc vessel angle	
0°–30°	2
>30°–60°	1
>60°	0
Disc edge to vessel distance	
<1.0 mm	2
1.0–2.5 mm	1
>2.5 mm	0

Sum of scores: <3, low risk; 3–4, moderate risk; >4, high risk.

t-test was employed to make comparisons between two groups of continuous variables, and analysis of variance (ANOVA) testing with Tukey *post-hoc* testing was employed for comparison of three or more groups. Statistical significance was determined (P<0.05).

Results

A total of 91 consecutive patients (60 males, 31 females; mean age 42.6±16.3 years; range, 18–80 years) were included in the study. Neither age, gender, ethnicity, height, nor weight correlated with the level of the iliocaval confluence (P>0.05). The confluence occurred superior to the L4–L5 disc space in 43 patients (47.3%), at the disc space in 25 patients (27.5%), and inferior to the disc space in 23 patients (25.3%). The mean disc diameter in the sagittal plane was 38.26±3.90 mm (range, 31.20–48.70 mm) and 54.79±5.50 mm (range, 40.80–68.85 mm) in the coronal plane. These values did not vary significantly between groups (P>0.05).

Anterior disc line to posterior vessel wall distance (Table 2)

The right CIV was located most posteriorly (highest risk), with a mean distance of 6.59±3.22 mm (range, −0.7 to 18.2 mm) from the anterior disc line. This did not vary based upon the iliocaval confluence. The IVC was the next most posteriorly-positioned vessel with a mean distance of 6.16±2.50 mm (range, 1.8–11.1 mm). The left CIV had a mean distance of 1.93±2.88 mm (range, −1.3 to 15.1 mm), which did not vary based on the level of the confluence.

Each artery was more anterior than the corresponding vein. The left CIA was posterior to the anterior disc line with a mean distance of 0.96±3.59 mm (range, −12.4 to 11.5 mm), whereas the aorta was anterior to this line with a mean distance of 0.06±1.37 mm (range, −2.3 to 2.0 mm). The right CIA was located anteriorly with a mean distance of 2.02±4.37 mm (range, −17.9 to 7.9 mm). There was no significant difference in the mean distance for any vessel when stratified by the level of the aortic bifurcation (P>0.05).

Table 2 Anterior disc line to vessel distance

Confluence level	R CIV	L CIV	IVC	R CIA	L CIA	Aorta
Superior to L4–L5 (mm) (n=43)	6.79±3.55 (−0.7 to 18.2)	2.15±3.14 (−1.3 to 15.1)	N/A	−1.67±5.07 (−17.9 to 7.9)	1.54±4.43 (−12.4 to 11.5)	N/A
At L4–L5 (mm) (n=25)	6.13±2.44 (2.4 to 11.9)	1.45±2.27 (−1.2 to 9.2)	N/A	−1.79±3.93 (−9.4 to 7.0)	1.14±1.99 (−2.3 to 5.9)	N/A
Inferior to L4–L5 (mm) (n=23)	N/A	N/A	6.16±2.50 (1.8 to 11.1)	−3.19±3.07 (−11.5 to 0.0)	−0.64±2.74 (−7.1 to 3.8)	0.67±1.15 (0.0 to 2.0)

Data are presented as mean ± SD (range). >5 mm = high risk (2 points); 0–5 mm = moderate risk (1 point); <0 mm = low risk (0 points). R, right; L, left; CIV, common iliac vein; IVC, inferior vena cava; CIA, common iliac artery; SD, standard deviation.

Table 3 Disc vessel angle

Confluence level	R CIV		L CIV		IVC		R CIA		L CIA		Aorta	
	RA	LA	RA	LA	RA	LA	RA	LA	RA	LA	RA	LA
Superior to L4–L5 (°) (n=43)	57.0±6.2 (7.0–71.9)	15.0±6.9 (4.0–52.3)	27.6±10.1 (7.0–42.3)	34.6±9.4 (19.4–47.9)	N/A	N/A	51.2±9.2 (17.2–66.3)	28.8±8.1 (13.2–49.1)	22.0±7.9 (6.9–30.4)	56.7±11.3 (28.4–84.8)	N/A	N/A
At L4–L5 (°) (n=25)	53.7±7.5 (34.3–65.7)	15.6±3.6 (12.0–20.0)	37.3±12.0 (24.2–59.8)	25.6±7.4 (14.3–42.2)	N/A	N/A	45.1±9.9 (20.9–69.6)	32.0±4.3 (24.3–38.0)	24.4±4.9 (13.9–36.2)	50.8±8.1 (38.4–69.2)	N/A	N/A
Inferior to L4–L5 (°) (n=23)	N/A	N/A	N/A	N/A	50.1±7.8 (35.8–53.9)	14.5±4.6 (5.9–23.8)	41.6±5.8 (31.6–47.4)	34.2±5.9 (25.1–43.2)	27.0±6.1 (14.9–31.6)	46.6±5.7 (35.6–53.9)	29.4±6.0 (22.3–35.1)	36.8±3.8 (32.2–41.3)

Data are presented as mean ± SD (range). 0°–30° = high risk (2 points); >30°–60° = moderate risk (1 point); >60° = low risk (0 points). RA, right approach; LA, left approach; R, right; L, left; CIV, common iliac vein; IVC, inferior vena cava; CIA, common iliac artery; SD, standard deviation.

DVA (Table 3)

The right CIV had a mean DVA of 55.8°±6.9° (range, 7.0°–71.9°) from a right-sided approach, and 15.2°±5.9° (range, 4.0°–52.3°) from a left-sided approach, which did not vary significantly based on the level of the iliocaval confluence (P>0.05). With a right-sided approach, the left CIV had a mean DVA of 27.6°±10.1° (range, 7.0°–42.3°) when the confluence was superior to the L4–L5 disc and 37.3°±12.0° (range, 24.2°–59.8°) when the confluence was at the level of the disc (P=0.001). With a left-sided approach, the left CIV had a mean DVA of 34.6°±9.4° (range, 19.4°–47.9°) when the confluence was superior to the L4–L5 disc and 25.6°±7.4° (range, 14.3°–42.2°) when the confluence was at the level of the disc (P<0.001). The IVC had a mean DVA of 50.1°±7.8° (range, 35.8°–53.9°) with a right-sided approach and 14.5°±4.6° (range, 5.9°–23.8°) with a left-sided approach (P<0.001).

The right CIA had a mean DVA of 49.0°±9.8° (range, 17.2°–69.6°) with a right-sided approach and 30.1°±7.1° (range, 13.2°–49.1°) with a left-sided approach, which did not vary significantly based on the level of the bifurcation (P>0.05). The left CIA had a mean DVA of 22.9°±7.0° (range, 6.9°–36.2°) with a right-sided approach and 54.5°±10.6° (range, 28.4°–84.8°) with a left-sided approach, which did not vary significantly based on the level of the bifurcation (P>0.05). Finally, the aorta had mean DVA of 29.4°±6.0° (range, 22.3°–35.1°) with a right-sided approach and 36.8°±3.8° (range, 32.2°–41.3°) with a left-sided approach (P<0.001).

Disc edge to vessel distance (Table 4)

The left CIV was closest to the L4–L5 disc with mean values of 0.30±0.51 mm (range, 0–2.1 mm) and 0.19±0.46 mm (range, 0–0.9 mm) when the confluence was located superior to and at the level of the L4–L5 disc, respectively (P=0.362). The IVC was the next closest vessel with a mean value of 0.46±0.82 mm (range, 0–2.6 mm). The right CIV was the furthest venous structure from the disc with a mean distance of 0.94±1.10 mm (range, 0–3.7 mm) when the confluence was located proximal to the disc and 0.51±0.67 mm (range,

Table 4 Disc edge to vessel distance

Confluence level	R CIV	L CIV	IVC	R CIA	L CIA	Aorta
Superior to L4–L5 (mm) (n=43)	0.94±1.10 (0–3.7)	0.30±0.51 (0–2.1)	N/A	4.57±4.21 (0–20.0)	3.11±2.82 (0–12.4)	N/A
At L4–L5 (mm) (n=25)	0.51±0.67 (0–2.0)	0.19±0.46 (0–0.9)	N/A	4.24±3.16 (0–9.6)	1.92±1.74 (0–6.6)	N/A
Inferior to L4–L5 (mm) (n=23)	N/A	N/A	0.46±0.82 (0–2.6)	3.39±3.07 (0–12.7)	2.21±2.29 (0–7.3)	1.06±0.86 (1.0–2.0)

Data are presented as mean ± SD (range). <1 mm = high risk (2 points); 1–2.5 mm = moderate risk (1 point); >2.5 mm = low risk (0 points). R, right; L, left; CIV, common iliac vein; IVC, inferior vena cava; CIA, common iliac artery; SD, standard deviation.

Table 5 Vascular injury risk stratification for each vessel/approach

Confluence level	R CIV		L CIV		IVC		R CIA		L CIA		Aorta	
	RA	LA	RA	LA	RA	LA	RA	LA	RA	LA	RA	LA
Superior to L4–L5 (n=43)	4.12±1.20 [5]	5.37±1.16 [6]	4.67±0.89 [5]	3.94±0.68 [4]	N/A	N/A	1.93±1.42 [2]	2.63±1.51 [3]	3.81±1.26 [4]	2.56±1.31 [3]	N/A	N/A
At L4–L5 (n=25)	4.04±0.79 [4]	5.28±0.68 [6]	3.94±0.78 [4]	4.64±0.70 [5]	N/A	N/A	2.12±1.39 [2]	2.44±1.45 [3]	3.64±1.15 [4]	2.64±1.15 [3]	N/A	N/A
Inferior to L4–L5 (n=23)	N/A	N/A	N/A	N/A	4.25±0.86 [5]	5.34±0.88 [6]	1.89±1.10 [2]	2.26±1.40 [2]	3.37±1.54 [4]	2.68±1.15 [3]	4.00±0.81 [4]	3.50±0.57 [4]
Overall risk (n=91)	4.08±1.01 [4]	5.30±0.90 [6]	4.51±0.85 [5]	4.33±0.75 [5]	4.25±0.86 [5]	5.34±0.88 [6]	2.03±1.44 [2]	2.54±1.47 [3]	3.68±1.20 [4]	2.63±1.26 [3]	4.00±0.81 [4]	3.50±0.57 [4]
P value	0.965	0.941	0.022*	0.006*	N/A	N/A	0.818	0.783	0.849	0.891	N/A	N/A

Data are presented as mean ± SD [median]. >4 points = high risk; 3–4 points = moderate risk; <3 points = low risk. *, statistically significant values. RA, right approach; LA, left approach; R, right; L, left; CIV, common iliac vein; IVC, inferior vena cava; CIA, common iliac artery; SD, standard deviation.

0–2.0 mm; P=0.051) when the confluence was at the disc level.

All arterial vessels were positioned further from the disc edge compared to their corresponding venous structures. The aorta was closest with a mean distance of 1.06±0.86 mm (range, 1.0–2.0 mm), followed by the left common iliac artery (CIA) (mean: 2.58±2.46 mm; range, 0–12.4 mm), and finally the right CIA (mean: 4.23±3.68 mm; range, 0–20.0 mm). There were no significant differences in the mean distance for any great artery when stratified by the level of the aortic bifurcation (P>0.05).

Overall risk stratification (Table 5, Figure 3)

The right CIV had a high risk of injury with both right-sided (VIRS score 4.08±1.01) and left-sided approaches (VIRS score 5.30±0.90) regardless of the level of iliocaval confluence. The left CIV had a moderate risk of injury with a left-sided approach when the iliocaval confluence was above the L4–L5 disc space but had a high risk of injury when the confluence was at the L4–L5 disc space (VIRS scores 3.94±0.68, and 4.64±0.70, respectively; P=0.006). The left CIV had a high risk of injury with a right-sided approach when the confluence was above the L4–L5 disc space but had a moderate risk of injury when the confluence was at the L4–L5 disc space (VIRS scores 4.67±0.89, and 3.94±0.78, respectively; P=0.022). The IVC had a high risk of injury with both right (VIRS score 4.25±0.86) and left-sided approaches (VIRS score 5.34±0.88). The aorta had a moderate risk of injury regardless of the right (VIRS score 4.00±0.81) or left-sided approaches (VIRS score 3.50±0.57). The left CIA had a moderate risk of injury with a right-sided approach (VIRS score 3.68±1.20) and a low risk of injury with a left-sided approach (VIRS score 2.63±1.26). The right CIA had a low risk of injury with both right (VIRS score 2.03±1.44) and left-sided approaches (VIRS score 2.54±1.47) regardless of the level of aortic bifurcation.

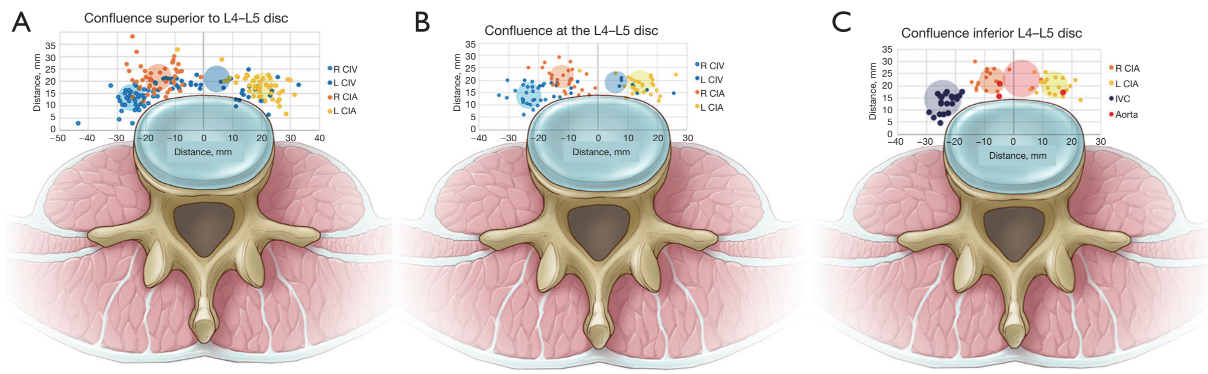

Figure 3 Scatterplot demonstrating overall location of each vessel when the confluence is (A) superior to the L4–L5 disc space, (B) at the L4–L5 disc space, and (C) inferior to the L4–L5 disc space. Illustration by Andy Rekito. R, right; L, left; CIV, common iliac vein; CIA, common iliac artery; IVC, inferior vena cava.

Discussion

The inherent advantages of less invasive lateral access spine surgery over traditional open techniques coupled with its expanding indications in the treatment of increasingly complex spinal disorders have led to widespread application of this approach and its techniques. A detailed anatomic study of the neurovascular structures is necessary to mitigate iatrogenic complications especially at the L4–L5 level as this level has the highest risk of injury to these structures. As direct visualization is often limited in less invasive approaches, an intimate understanding of the surrounding anatomy is paramount. In prior studies, the neural anatomy has been described in detail and surgical instrumentation for this approach typically utilizes neurologic monitoring to minimize the risk of injury (18,19,32-38). On the other hand, a detailed account of the vascular anatomy pertaining to this approach is lacking. We thus evaluated the position of the major abdominopelvic vessels as they pertain to the lateral transpsoas approach to the L4–L5 disc space.

Few studies have previously examined the vascular anatomy of the lumbar spine as it pertains to the LLIF approach. Hu *et al.* used MRI scans to evaluate the disc edge to vessel distance of 48 patients and found that both the IVC and the aorta were located closer to the spinal column when progressing distally from L1 to L5 (29). Yusof *et al.* evaluated the lumbar spine MRI scans of 100 patients to determine the feasibility of the lateral transpsoas approach at L3–L4 and L4–L5 from the left and the right side (28). They found that the IVC progressed posteriorly from the L3–L4 disc to the L4–L5 disc. They concluded that this approach was feasible bilaterally at L3–L4, but only from the left side at the L4–L5 level. Kepler *et al.* examined the anterior disc line to vessel distance on MRI scans from 43 patients and described the position of the psoas muscle, lumbar plexus, femoral nerve, IVC, and right CIV (39). They found that the L4–L5 level was at highest risk of neurovascular injury with 21% of left-sided approaches and 44% of right-sided approaches having at risk surgical windows. Both Yusof *et al.* and Kepler *et al.* examined the risk of vascular injury with respect to the direct, ipsilateral approach. They did not evaluate the risk of indirect vascular injury from the contralateral approach. Moreover, angular measurements were not obtained by these authors. In our experience, slight anterior angulation of the disc preparation instrumentation increases the likelihood of contralateral vascular injury. The current study evaluated the risk of vascular injury from both a direct and indirect approach. We also evaluated angular measurements of the disc vertebral angle in combination the anterior disc line to posterior vessel wall distance and with the disc edge to vessel distance to assess the risk of vascular injury.

Our study demonstrated that the right CIV and the IVC are consistently the most at-risk for injury during transpsoas LLIF regardless of a right- or left-sided approach as they are the most posteriorly located, have the narrowest angle of surgical trajectory, and are frequently within one millimeter of the disc edge. However, the left CIV had a moderate risk of injury with a left-sided approach when the iliocaval confluence was above the L4–L5 disc space and had a high risk of injury when the confluence was at the L4–L5 disc space (*Table 5*). On the other hand, with a right-sided approach, the left CIV had a high risk of injury when the confluence was above the L4–L5 disc space and had a moderate risk of injury when the confluence was at the L4–L5 disc space. The arterial vessels, by contrast, were all at low or moderate risk for injury as they were relatively more anterior, further from the line of surgical dissection at an angle greater than 30 degrees from the disc edge, and a greater distance from the disc.

This study has several limitations. First, the data presented is specific to the L4–L5 disc level and therefore cannot be applied to LLIF procedures at other levels. Additionally, MRI evaluates the patient in the supine position, whereas the surgery is performed from the lateral position. Therefore, the orientation of the vessels relative to the spine may change at the time of surgery. While this study evaluated the mean position of each vessel, it should be noted that significant normal anatomic variation exists between individual patients (*Figure 3*). Additionally, our risk assessment is theoretical as this is an anatomic study without clinical data; thus, future clinical cohort studies will be valuable for assessing the applicability of this methodology in practice. Furthermore, our study was also limited by a relatively small sample size.

Despite these limitations, the current study provides a detailed description of the vascular anatomy at the L4–L5 disc as it pertains to the lateral transpsoas approach. Furthermore, it offers an objective method for the preoperative evaluation of each great vessel while considering normal variation between individuals. Its application in the surgical treatment of spinal disorders via the lateral approach has the potential to enhance the safety of this technique as its application continues to expand. Further studies demonstrating the external validity of this data may be necessary prior to its application in practice.

Conclusions

The right CIV and the IVC are at high risk of injury at L4–L5 via a transpsoas LLIF from both a right- and left-sided approach regardless of the level of the iliocaval confluence. The left CIV has a high risk for injury with a right-sided approach when the iliocaval confluence was above the L4–L5 disc and with a left-sided approach when the confluence occurs at the level of the L4–L5 disc. There are significant vascular anatomic variations at the L4–L5 disc level and a proper VIRS can be performed utilizing a combination of anterior disc line to posterior vessel wall distance, DVA, and disc edge to vessel distance, on the axial MRI.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://jss.amegroups.com/article/view/10.21037/jss-23-94/rc

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jss.amegroups.com/article/view/10.21037/jss-23-94/coif). A.J.G. has the following disclosures that are unrelated to this article: Partner of Premier Brain & Spine. R.A.W.M. has the following disclosures that are unrelated to this paper: Royalties from Globus Medical. The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by institutional review board of UT Health Department of Orthopedic Surgery (Approval No. HSC-MS-12-0370) and individual consent for this retrospective analysis was waived.

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