Spine

SPINE Volume 39, Number 14, pp E811-E816

ANATOMY

The Morphometric Study of L3–L4 and L4–L5 Lumbar Spine in Asian Population Using Magnetic Resonance Imaging

Feasibility Analysis for Transpsoas Lumbar Interbody Fusion

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Study Design. Cross-sectional study on the measurement of relevant magnetic resonance imaging parameters in 100 patients presented for lumbar spine assessment.

Objective. To determine anatomical position of lumbar plexus and major blood vessels in relation to vertebral body and anterior edge of psoas muscle at L3–L4 and L4–L5 and to define the safe working zone for transpsoas approach for lumbar fusion.

Summary of Background Data. Lateral transpsoas lumbar interbody fusion has been shown to be safe and provides alternative for lumbar fusion. However, proximity of neurovascular structures may not allow a safe passage for this procedure in the Asian population.

Methods. Relevant parameters were measured from axial magnetic resonance images and analyzed, including the psoas muscle and vertebrae endplate diameters, lumbar plexus and psoas muscle distance, lumbar plexus and vertebra body distance, and vena cava to the anterior vertebrae body diameters.

Results. The mean anteroposterior diameters of the right and left psoas muscle ranged from 44.0 to 58.6 mm and 44.8 to 54.0 mm, respectively. The mean anteroposterior diameters of vertebra endplate of L3, L4, and L5 were 38.2 mm, 39.3 mm, and 41.4 mm, respectively. The mean distance of posterior border of vena cava from the vertebra body was 4.5 mm at L3–L4 and 14.1 mm at L4–L5.

Conclusion. L3–L4 fusion is feasible at both sides in both sexes; however, at L4–L5 level, the procedure is feasible only on the left side. The safe working zone for transpsoas approach to lumbar spine is significantly narrower at L4–L5 in both sexes. Anterior edge of psoas muscle can be used as a reliable guide to locate lumbar plexus within psoas muscle.

Key words: transpsoas approach, lumbar fusion, feasibility, Asian, magnetic resonance images.

Level of Evidence: N/A

Spine 2014;39:E811–E816

Spinal fusion is commonly performed in patients with degenerative spine diseases, spinal deformity, and fractures, which can be achieved through posterior, lateral, or anterior approach. There are few complications associated with spinal interbody fusion. Posterior lumbar interbody fusion is associated with incidence of durotomy and nerve roots injury because of the need of retraction of the dural sac.[1] Transforaminal lumbar interbody fusion procedure is also associated with accidental durotomy and dysesthetic pain syndromes from nerve roots injuries.[2] Vascular complications, ureteral injuries, sexual dysfunction, and bowel injury have been reported during anterior lumbar interbody fusion procedures.[3]

Lumbar interbody fusion using lateral transpsoas approach is a recent technique developed to prevent complications associated with traditional or minimally invasive anterior or posterior approaches to the lumbar spine. It is gaining popularity as a safer alternative for lumbar interbody fusion. The clinical outcomes of this surgical technique were first published in 2007.[4] The complication rate associated with this approach was considered low with proper technique and correct indications. Lumbar fusion using less invasive transpsoas approach resulted in less tissue disruption and, therefore, reduced postoperative pain, shorter hospital stays, quicker recovery, and better improvement in functional scores.[5]

A substantial number of patients experienced hip and thigh weakness and numbness after the procedure,[6] probably because of the proximity of the retroperitoneal vessels and lumbar plexus to the surgical approach. To date, there are no reported cases of retroperitoneal vascular injury after

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Acknowledgment date: October 23, 2013. First revision date: January 25, 2014. Second revision date: March 5, 2014. Acceptance date: March 31, 2014.

The manuscript submitted does not contain information about medical device(s)/drug(s).

No funds were received in support of this work.

No relevant financial activities outside the submitted work.

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DOI: 10.1097/BRS.0000000000000368

transpsoas approach. However, increased risk of vascular injury can be expected with the extended indications of this approach, especially for degenerative scoliosis.[7]

Lumbar vertebrae of L3–L4 and L4–L5 are common spinal levels undergoing symptomatic degenerative process and surgically approachable using this technique.[8] However, a high-riding iliac crest may render the L4–L5 disk space inaccessible. Because of anatomical restrictions, L5–S1 fusion using this approach is technically not feasible.[9,10] Adequate related anatomic knowledge to this approach is essential to minimize the complications. There has been a few studies done on this, especially involving the Caucasians.[1] Similar study in Asian population has not been reported, and the safe working zone (SWZ) for lumbar interbody fusion using lateral transpsoas approach has never been defined. It is imperative to define the surgical feasibility in Asian patients because the spinal morphometry in this population might be different, as we found in earlier studies.[11,12] Previous findings confirmed that many spinal parameters in Asians were significantly smaller than those in Caucasians including thoracic pedicle length, transverse pedicle angle, and transverse pedicle outer diameter.[12] It should be noted that these findings may not be precisely applicable to non-Asians. Our study is to determine the anatomical position of lumbar plexus and major blood vessels in relation to vertebral body and anterior edge of psoas muscle at L3–L4 and L4–L5 and define the SWZ for lumbar interbody fusion using transpsoas approach for our population. Because of anatomical restriction at L5–S1, this level was not included in our analysis.[9,10]

MATERIALS AND METHODS

The studied patients were randomly chosen from our hospital registry, which were seen for lumbar spine assessment between 2009 and 2013. Those who had lumbar spinal abnormalities (congenital deformity, trauma, infection, primary or secondary tumor) were excluded from this study. The axial magnetic resonance images were obtained using magnetic resonance imaging machine (GE Medical Systems, Milwaukee, WI).

The patient's lumbar magnetic resonance imaging that fulfilled the inclusion and exclusion criteria was selected for this study. The images were obtained from both sexes aged between 27 and 86 years. Those who had spinal deformity, fractures, metastasis, spinal infection, and psoas muscle pathology were excluded from this study. Their sociodemographics (age and sex) and the diagnoses were documented. Sagittal T1-, T2-, and T2-weighted fat-suppressed sequences were obtained at 3.0- to 3.5-mm slice intervals. Coronal T2-weighted images were obtained at 3-mm slice intervals. All images were acquired on a superconducting closed 3.0 T magnet. These images were appropriately angled to the disc space, and measurement was determined using the PACS (Picture Archiving and Communication Systems; GE Medical Systems, Milwaukee, WI) software computer digitalizer.

Relevant parameters required were measured from axial T2 images at middisc level cuts at L3–L4 and L4–L5 (Figure 1).

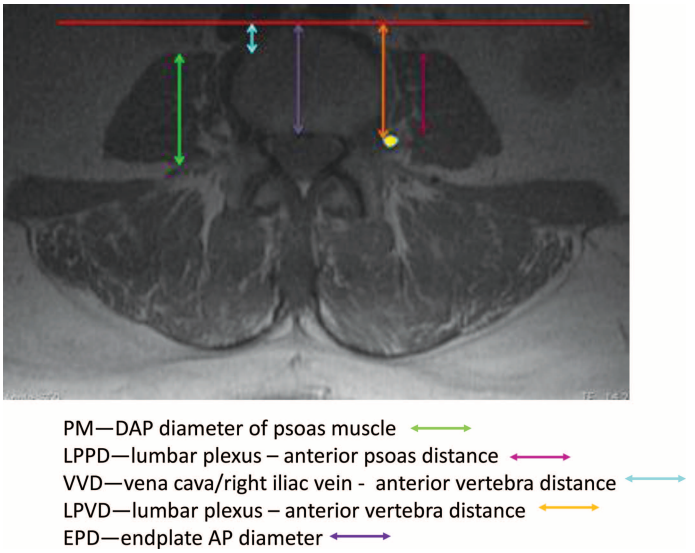

Figure 1. Measurements of relevant parameters, PMD, LPPD, VVD, LPVD, and EPD, at L3–L4 and L4–L5 from magnetic resonance images.

1. Anterior-posterior diameter of psoas muscle (PMD)
2. Anterior-posterior diameter of vertebrae endplate (EPD)
3. Distance between the lumbar plexus and anterior border of psoas muscle (LPPD)
4. Distance between the lumbar plexus and anterior border of vertebra body (LPVD)
5. Distance between posterior edges of vena cava or right iliac vein to the anterior vertebrae body (VVD)

The SWZ was estimated by measuring the distance between the posterior border of the inferior vena cava (IVC) and the anterior border of the lumbar plexus for the right-side approach. For the left-side approach, the distance was measured between the anterior border of the psoas muscle and the anterior border of the lumbar plexus.

All the measurements were repeated 3 times and performed by 1 investigator. The average of the measurements was taken for analysis.

RESULTS

There were 100 patients involved in this study. Forty-eight (48.0%) of the subjects were female, whereas the remaining 52 (52.0%) subjects were male (Table 1). The mean right PMDs were 48.4 mm (SD = 2.0 mm) at L3–L4 and 48.8 mm (SD = 2.4) at L4–L5, ranging from 44.0 to 58.6 mm whereas the left PMDs were 48.9 mm (SD = 1.8) at L3–L4 and 48.7 mm (SD = 1.8) at L4–L5, ranging from 44.8 to 54.0 mm. The mean PMDs at L3–L4 and L4–L5 were wider in male patients ($P < 0.001$). There was no significant difference of PMD at L3–L4 and L4–L5 between the right side and the left side in male patients; however, it was statistically significant in females.

The mean EPDs of L3, L4, and L5 were 38.2 mm (SD = 1.7), 39.3 mm (SD = 1.7), and 41.4 mm (SD = 1.7),

TABLE 1. Demographic Data of the Patients Involved in the Study

	Mean (SD)		
	Female (n = 48)	Male (n = 52)	Overall Mean (SD)
Age, yr	64.50 (28.0)	59.00 (26.0)	61.00 (28.0)
Diagnosis			
Degenerative spine disease	23 (47.9)	25 (48.1)	48 (48.0)
Herniated disc	8 (16.7)	5 (9.6)	13 (13.0)
Spinal stenosis	15 (31.3)	9(17.3)	24 (24.0)
Trauma	2 (4.2)	13 (25.0)	15 (15.0)

respectively. There was statistically significant difference of EPD at L3, L4, and L5 between both sexes.

The mean LPPD of the right side was 33.5 mm (SD = 1.7) at L3–L4 and 34.9 mm (SD = 1.8) at L4–L5 (28.2–38.3 mm), whereas on the left side, it was 32.4 mm (SD = 1.6) at L3–L4 and 34.4 mm (SD = 1.7) at L4–L5 (28.0–38.7 mm). The LPVD of the right side was 29.0 mm (SD = 1.9) at L3–L4 and 29.0 mm (SD = 1.9) at L4–L5 (18.7–34.8 mm). The left LPVD was 28.6 mm (SD = 1.7) at L3–L4 and 22.6 mm (SD = 1.8) at L4–L5 (19.1–34.2 mm). LPPD of the right and left sides was significantly different at both levels in both sexes, and the difference of LPPD at L3–L4 and L4–L5 in both sexes was also significant.

The mean VVD was 4.5 mm (SD = 1.2) at L3–L4 and 14.1 mm (SD = 1.6) at L4–L5, and the difference was significantly different in both sexes. The distance was wider in male patients (Table 2).

The SWZ was found to be significantly different between both sides at L3–L4 and L4–L5 levels regardless of the patients' sex. Generally, narrower SWZ was seen on the right side, at L4–L5 level, and in female patients (Table 3).

DISCUSSION

Lumbar interbody fusion accomplishes the goal of achieving satisfactory spinal fusion and maintenance of sagittal balance of the patients. Minimally invasive lateral transpsoas approach is a recent technique for lumbar interbody fusion. The main challenge of this procedure is to assess the correct placement of the implant without causing injury to the major vessels and lumbar nerve roots. Because the ventral nerve roots and the lumbar plexus are within the psoas muscles, this approach may injure these structures during the access and retraction of psoas muscle.[1]

There were few published studies evaluating the locations of lumbar plexus in relation to psoas muscle to map this nerve and its possible variations. We decided to evaluate the feasibility and safety of this approach as it would be very useful for our population, as most of the studies were performed in Caucasians. We suspect that there is possible anatomical variation of lumbar plexus and other related anatomies in our populations compared with the western population.[13] There was no well-documented study that looked into anatomical location of lumbar plexus and the SWZ for this approach in Asian populations.

We evaluated the SWZ for lateral transpsoas approach at L3–L4 and L4–L5, because these levels are commonly affected in degenerative spine disease and appropriate for this approach.[14] This approach is not feasible for L5–S1[9,10]; therefore, this level was not evaluated in this study.

The SWZ for lateral transpsoas approach was defined as area of psoas muscle (mm) that is free of retroperitoneal vessels anteriorly and lumbar plexus posteriorly in relation to lateral border of the vertebra body. The IVC overlaps the anterolateral border of vertebra body at the right side. Therefore, the SWZ was smaller on the right side because both the lumbar plexus and the retroperitoneal vessels became the possible structures at risk. On the left side, lumbar plexus was the only structure at risk during the procedure.

The SWZs in female patients were significantly larger at L3–L4 (23.80 mm) than those at L4–L5 (9.09 mm). Similar trend was seen in male patients in whom the SWZ was significantly smaller at the level of L4–L5 (8.95 mm) than that at the level of L3–L4 (25.12 mm). This was most probably due to the more anteriorly placed lumbar plexus within the psoas muscle at L4–L5 as it travels down the body. Surprisingly, the SWZ on the right side at L4–L5 in males (8.95 mm) was smaller than that in females (9.09 mm), which might signify an increased risk of possible neurovascular structures injury, despite having a larger PMD. The more posteriorly located IVC in male patients and more anteriorly located lumbar plexus significantly reduced the SWZ on the right-sided approach at L4–L5 level.

On the left side, the SWZ was bigger in males than in females at both L3–L4 and L4–L5. In both groups, it was significantly narrower at the right side at both L3–L4 and L4–L5 levels. Therefore, transpsoas approach from the right side is more risky. Having the narrowest SWZ, transpsoas approach to the L4–L5 disc from the right side carries the highest risk. Therefore, transpsoas interbody fusion using the left approach was preferred by most surgeons,[15] because it minimized the risk of vascular injury. Other study showed similar findings.[1] In addition, our population was found to have smaller anteroposterior PMD and narrower SWZ, especially at the right side of L4–L5 level. The instruments currently available

TABLE 2. The Measurements (Mean) of PMD, LPPD, VVD, LPVD, and EPD at L3–L4 and L4–L5

	Female (n = 48) Mean (SD)		Male (n = 52) Mean (SD)		Overall Mean (SD)	
	Right	Left	Right	Left	Right	Left
PMD						
L3–L4 (mm)	46.90 (1.48)	47.59 (1.23)	49.71 (1.37)	50.12 (1.26)	48.36 (2.00)	48.90 (1.77)
L4–L5 (mm)	47.24 (1.37)	47.55 (1.23)	50.27 (2.32)	49.73 (1.49)	48.81 (2.44)	48.69 (1.75)
LPPD						
L3–L4 (mm)	32.29 (1.39)	34.43 (1.30)	34.63 (1.18)	33.36 (1.30)	33.51 (1.73)	32.44 (1.62)
L4–L5 (mm)	33.72 (1.45)	33.30 (1.43)	36.01 (1.40)	35.34 (1.37)	34.91 (1.82)	34.36 (1.73)
LPVD						
L3–L4 (mm)	27.64 (1.28)	27.40 (1.18)	30.21 (1.44)	29.65 (1.29)	28.97 (1.87)	28.57 (1.67)
L4–L5 (mm)	22.13 (1.81)	21.49 (1.39)	24.02 (1.45)	23.69 (1.43)	23.11 (1.88)	22.63 (1.79)
VVD						
L3–L4 (mm)	3.84 (0.88)		5.09 (1.11)		4.49 (1.18)	
L4–L5 (mm)	13.03 (1.34)		15.07 (1.24)		14.09 (1.64)	
EPD						
L3	37.23 (1.35)		39.09 (1.54)		38.20 (1.72)	
L4	38.24 (1.39)		40.28 (1.41)		39.30 (1.73)	
L5	40.37 (1.44)		42.36 (1.32)		41.41 (1.70)	

PMD indicates psoas muscle diameter; LPPD, lumbar plexus—psoas distance; LPVD, lumbar plexus—vertebra distance; VVD, vena cava/right iliac vein—anterior vertebra distance; EPD, endplate diameter.

for interbody fusion using this approach were based on the measurements performed on Caucasian, which is probably inappropriate for our populations.

We also analyzed the location of lumbar plexus in relation to anterior border of psoas muscle. The measurements showed that the lumbar plexus was constantly located at the posterior one-third of the psoas muscles bilaterally. This finding was true for both male and female patients. Therefore, anterior border of psoas muscle can be used as a reliable marker to estimate the location of lumbar plexus within the psoas muscle and, therefore, the safety of the procedure.

Our results that suggested that lateral transpsoas approach from the right, especially at L4–L5, carries the highest risk of lumbar nerve injury had been shown in other study.[13] Our findings also showed that the lumbar plexus has a more ventral location within psoas muscle as it travels from L2 to L5 and, hence, renders it more susceptible for tractional injury at lower lumbar region. Similar findings had been reported.[16,17] However, the difference in location between the right and left lumbar plexus was not reported by the authors. The distance between lumbar plexus and anterior border of the psoas muscle (LPPD) was also significantly wider in male patients.

The anteroposterior PMD was also measured. The diameter of the muscle increased significantly from L3 to L5 but the diameter of the muscles was similar at both sides. These findings were consistent with other study.[13] The muscles were significantly larger in male patients.

Anterior border of vertebra body is an important reference point because many procedures were performed using

TABLE 3. The Safe Working Zone at L3–L4 and L4–L5 Measured in the Study

Level		Female (mm)		Male (mm)	
L3–L4	Right	23.8 mm	$P < 0.001$	25.1	$P < 0.001$
	Left	27.4 mm		29.7	
L4–L5	Right	9.1 mm	$P < 0.001$	8.9	$P < 0.001$
	Left	21.5 mm		23.7	

minimally invasive technique with the assistance of image intensifier; therefore, LPVD was also measured. This would be helpful to determine the entry point into the psoas muscle.[18] Our findings showed that this measurement was significantly wider in males. This was attributed to the wider PMD in these patients, especially at L4–L5. This finding supported the fact that female patients have greater risk of lumbar plexus injury using blunt dissection of psoas muscle in minimally invasive technique.

The retroperitoneal vessels were located on the right side and more posterior to the psoas muscle and vertebra body.[19] Because the right iliac vein was constantly located more anteriorly, the IVC was taken as the reference point as it has a higher chance of injury during splitting of the psoas muscle.[1] The VVD was generally larger in males than in females and wider at L4–L5 than at L3–L4. Lumbar plexus is located in a more ventral location as it travels down from L3–L4 to L4–L5, and this narrows down the safe zone in L4–L5 as compared with L3–L4 although the VVD is larger in L4–L5 level. Therefore, the risk of injuring IVC during transpsoas approach is higher at L4–L5 than at L3–L4.[20,21]

Lumbar fusion using cages or spacers has been widely used. As it involves retraction of psoas muscle to accommodate the passage of the spacer, the feasibility for fusion using transpsoas approach should be considered carefully. Injury to the neurovascular injury is possible, especially at L4–L5 with excessive retraction of the psoas muscle. However, it has been shown that a spacer of less than 18 mm will increase the risk of subsidence, especially in osteoporotic bones.[22] Therefore, an optimum spacer size is critical. Based on our findings, L3–L4 fusion is feasible at both sides in both sexes as the SWZ was more than 18 mm. However, at L4–L5 level, the procedure is feasible only from the left side, because the safe zone for right-sided approach at L4–L5 in both male (8.95 mm) and female (9.09) subjects was narrower than the minimum diameter (18 mm) required.

This study is not without limitations. First, this is a magnetic resonance imaging–based study in which the procedure was performed in supine position. The measurements of the parameters might not be accurate because the lateral transpsoas approach is performed in lateral decubitus position. Second, the measurements in this study involved L3–L4 and L4–L5 levels only. Although these levels are commonly involved in degenerative disorders, similar evaluation at L1–L2 and L2–L3 vertebra would be useful. Third, this study does not estimate the minimum retraction allowed to avoid complications associated with compressive injury to the adjacent neurovascular structures.

This study is to evaluate the safety and accessibility of this emerging technique in our population. On the basis of this study, we found that the SWZ for transpsoas approach to lumbar spine was significantly narrower at L4–L5 in both sexes, especially on the right side. The SWZ was significantly narrower in females. It should be noted that as these data were obtained from Asian subjects, they may not be precisely applicable to non-Asians. The surgeons should be aware of this variation whenever they decide to use this technique in our population.

➢ Key Points

- ❑ L3–L4 fusion is feasible at both sides in both sexes; however, at L4–L5 level, the procedure is feasible only on the left side.
- ❑ The SWZ for transpsoas approach to lumbar spine is significantly narrower at L4–L5 in both sexes.
- ❑ The SWZ for transpsoas approach to lumbar spine is significantly narrower on the right side due to retroperitoneal vascular structures in both sexes.
- ❑ The SWZ for transpsoas approach to lumbar spine is significantly narrower in females.
- ❑ Anterior edge of psoas muscle can be used as a reliable guide to locate lumbar plexus within psoas muscle.

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