Eur Spine J
DOI 10.1007/s00586-015-3847-8

ORIGINAL ARTICLE

A MRI study of lumbar plexus with respect to the lateral transpsoas approach to the lumbar spine

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Received: 16 August 2014 / Revised: 18 January 2015 / Accepted: 26 February 2015

Abstract

Purpose To evaluate the relative position between lumbar plexus and access corridor of minimally invasive lateral transpsoas lumbar approach, as well as the approach safety.

Methods Three-dimensional fast imaging employing steady-state acquisition (3D FIESTA) sequence images of lumbar spine were obtained from 58 patients with lumbar degenerative diseases for reconstruction to analyze the distribution of lumbar plexus from L1–L2 to L4–L5 level with respect to the transpsoas lumbar approach. The axial image distance (AID) between the anterior edge of lumbar plexus and the sagittal central perpendicular line (SCPL) of disc was measured. SCPL was drawn perpendicularly to the sagittal plane of intervertebral disc and it passed through its central point, which is initial dilator trajectory for transpsoas approach. As related to the SCPL of disc, the distance with a positive value was set to indicate neural tissue posterior to it, while anterior to it was represented by a negative value.

Results In relation to SCPL of disc, the AID of lumbar plexus was measured 13.01 ± 1.70, 8.61 ± 2.26, 1.12 ± 2.37 and -5.42 ± 3.26 mm from L1–L2 to L4–L5 level, respectively, while the AID of genitofemoral nerve was recorded -1.13 ± 2.87, -5.78 ± 2.33 and -10.53 ± 3.30 mm from L2–L3 to L4–L5 level accordingly.

Conclusion With respect to the SCPL of disc, a trajectory of guide wire or a radiographic reference landmark to place working channel, lumbar plexus lies posteriorly to it from L1–L2 to L3–L4 level and shifts anteriorly to it at L4–L5 level, while genitofemoral nerve locates anteriorly to the SCPL from L2–L3 to L4–L5 level. Neural retraction may take place during sequential dilation of access corridor especially at L4–L5 level.

Keywords Lateral lumbar interbody fusion · Lateral transpsoas approach · Lumbar plexus · Magnetic resonance imaging

Introduction

Lateral lumbar interbody fusion (LLIF) [1, 2], as a minimally invasive lateral transpsoas approach, has shown its advantage to avoid anterior or posterior approach-related complications [1–3]. However, this approach carries the risk of injury to lumbar plexus when penetrating and dilating psoas major associated with excessive neural retraction and psoas trauma, which induces transient postoperative thigh pain or numbness, even with the aid of electromyography (EMG) neuromonitoring [4, 5].

There is significance to evaluate the relative position between lumbar plexus and working channel to reduce or avoid nerve injury when establishing the lateral approach. No published MRI studies now available have analyzed the relative position between lumbar plexus and access corridor during LLIF.

Electronic supplementary material The online version of this article (doi:10.1007/s00586-015-3847-8) contains supplementary material, which is available to authorized users.

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Three-dimensional (3D) reconstruction imaging technology is applied to lumbar plexus imaging in this study to evaluate the relative position between lumbar plexus and working channel at various levels according to minimally invasive lateral transpsoas approach as well as the approach safety.

Materials and methods

Inclusion and exclusion criteria

Consent was informed of patients with low back pain and/or radicular pain or intermittent claudication, who were planned for MRI examination and included in this research. Patients with degenerative lumbar scoliosis >10°, spondylolisthesis >grade 1, trauma, lumbar infection and tumors, arterial insufficiency in legs, polyneuropathy, prior history of idiopathic scoliosis, previous retroperitoneal surgery and previous lumbar fusion and/or internal fixation were excluded. This protocol was approved by the Third Affiliated Hospital of Sun Yat-sen University. From July 2012 to December 2012, 58 patients were included in the present research consisting of 25 males and 33 females and their average age stood at 53.24 ± 17.19 years old.

Scanning and measurements

The isotropic MRI scans were performed continuously from L1 to L5 vertebrae on a 1.5-Tesla scanner (Twinspeed Excite II, GE, Milwaukee, USA) using a four-channel Spine Phase Array coil. Axial 3D fast imaging employing steady-state acquisition (3D FIESTA) sequences (TE = 1.2 ms, TR = 3.5 ms, FA = 55, BW = 62.5 kHz, Matrix = 192 × 192, FOV = 190 mm, thickness = 1 mm, NEX = 4) and coronal 3D FIESTA sequences (TE = 1.2 ms, TR = 3.5 ms, FA = 55, BW = 62.5 kHz, Matrix = 160 × 160, FOV = 190 mm, thickness = 1.2 mm, NEX = 4) were obtained. The total number of intervertebral space measured was 232 levels from L1–L2 to L4–L5.

All original images were input into advantage workstation (AW4.1, GE, Milwaukee, USA) to achieve sagittal, coronal and axial images with multiplanar reconstruction (MPR) technique. Adjust the thickness of reconstruction plane to 3.3 mm so as to clearly display the lumbar plexus. On 3D FIESTA images, lumbar plexus that run obliquely downward from intracanal to extraforaminal was shown as low-signal-intensity structure against a background of the cerebrospinal fluid or fat tissue, which was presented as high-signal intensity [6, 7]. 3D FIESTA was performed by tracing the entire running course of the nerve root from the intervertebral foramen to the trunks of the lumbar plexus that resided in the psoas muscles on consecutive sliced images. On the basis of familiarity with the relevant neuroanatomy, lumbar plexus can be discernment easily and accurately according to their shape and running course from various angles by 3D reconstruction images.

In accordance with actual lateral transpsoas approach, the present study located the mid-disc space from L1–L2 to L4–L5 level as the measurement plane by reconstructed sagittal images, which appropriately ran parallel to the endplates (Fig. 1). Based on isotropy, which represented the characteristic of 3D FIESTA sequence, the spatial location of each point in all reconstructed images was consistent, while each point in the 3D system of coordinates corresponded to the unique point coordinates. The sufficient diagnostic information of intrapsoas nerves was obtained to identify the point coordinates of the anterior edge of lumbar plexus via diagnosis confirmed by reconstructed axial and coronal images combined. The sagittal central perpendicular line (SCPL) of disc was drawn perpendicularly to the sagittal plane of intervertebral disc and it passed through its central point which is initial dilator trajectory for transpsoas approach, bisecting the disc into anterior–posterior parts. The point coordinates of SCPL were measured in relation to anterior and posterior borders of intervertebral disc via reconstructed images.

The axial image distance (AID) between the anterior edge of lumbar plexus and the SCPL of disc was determined at various levels using the distance formula (Figs. 2, 3).

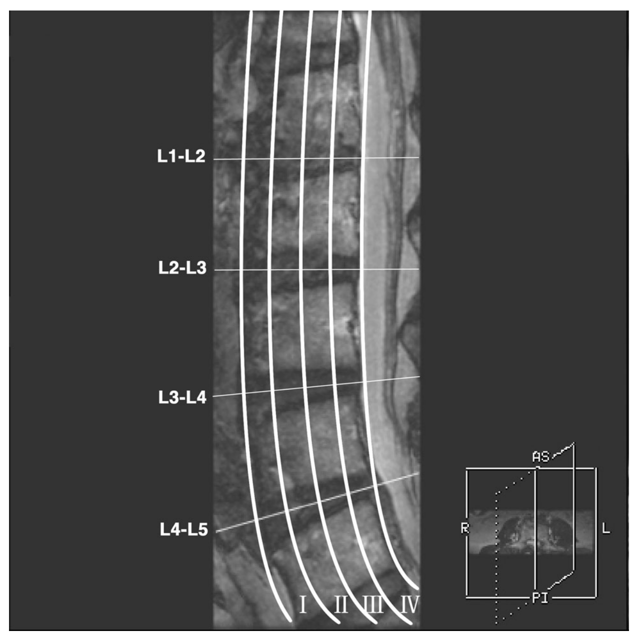

Fig. 1 The reconstructed sagittal image of 3D FIESTA sequence showed that the measurement plane located at the mid-disc space from L1–L2 to L4–L5 level, which appropriately ran parallel to the endplates. Lumbar intervertebral spaces were divided into four zones (zones I–IV) from anterior to posterior

Suppose point $A(x_1, y_1, z_1)$ represented the point coordinates of the anterior edge of the lumbar plexus and point $B(x_2, y_2, z_2)$, the point coordinates of intersection between the SCPL and its perpendicular, which ran across point $A(x_1, y_1, z_1)$. The formula for the distance (d) between points A and B in space (Eq. 1):

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \quad (1)$$

Measurements were presented in millimeters to offer reference for the establishment of lateral transpsoas lumbar approach. With respect to the SCPL of disc, the distance with a positive value indicated neural tissue posterior to it, while anterior to it was represented by a negative value. All measurements were accomplished independently by two viewers, including a senior musculoskeletal radiologist and a professionally trained spine surgeon who was experienced in LLIF procedure. Preliminary experiments were carried out to standardize the image diagnosis for the sake of consistency of final results. According to Uribe's method [8], lumbar intervertebral spaces were divided into four zones from the anterior to the posterior edges as follows: Zone I (anterior quarter), Zone II (middle anterior quarter), Zone III (posterior middle quarter), and Zone IV (posterior quarter) (Fig. 1). The distribution of lumbar plexus at each zone of each lumbar intervertebral space was also analyzed based on the MRI images and the AIDs.

Statistical analysis

Statistical analysis was performed using SPSS 17.0 (SPSS Inc, Chicago, IL, USA) with an α value of 0.05. $P < 0.05$ was considered statistically significant. All results were reported as mean ± standard deviation and 95 % confidence intervals (CIs). One-factor analysis of variance was used to compare differences of AID among various levels. The differences of AID under factors of distinct reconstruction methods and genders were evaluated by Student's t test. Interobserver and intraobserver reliability was evaluated with the use of the interclass correlation coefficient (ICC).

Results

Position of lumbar plexus

The AID between the anterior edge of lumbar plexus and SCPL of disc was, respectively, 13.01 ± 1.70,

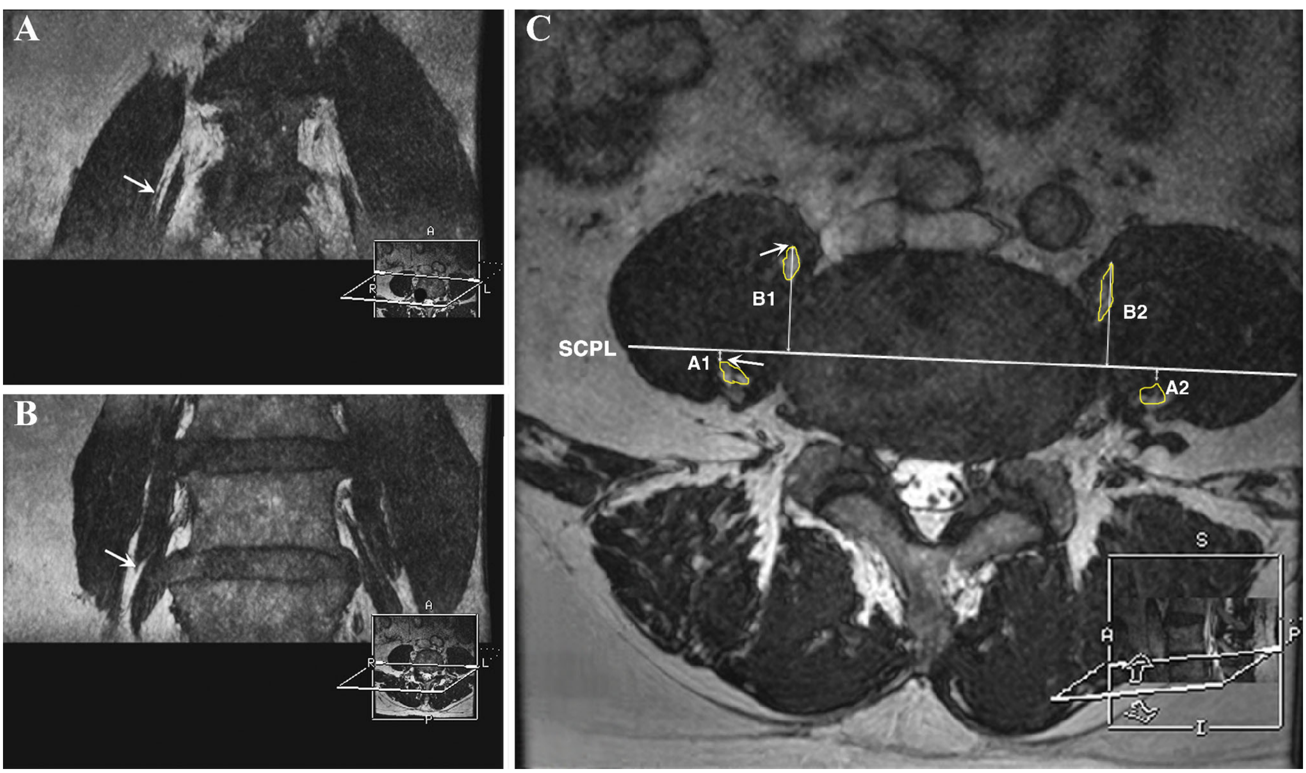

Fig. 2 The measurements at L4–L5 level by axial image reconstruction. The *arrow* in the reconstructed coronal image illustrated the anterior edge of genitofemoral nerve (**a**) and lumbar plexus (**b**) on the *right side* of the intervertebral space. The *arrow* in the original axial image (**c**) demonstrated the anterior edge of lumbar plexus and genitofemoral nerve on the *right side* of the intervertebral space, respectively. Distances $A1$, $A2$ and $B1$, $B2$ represented the AIDs from the anterior edge of lumbar plexus and genitofemoral nerve to the SCPL of disc on both sides of the intervertebral space, respectively. *AID* the axial image distance, *SCPL* the sagittal central perpendicular line

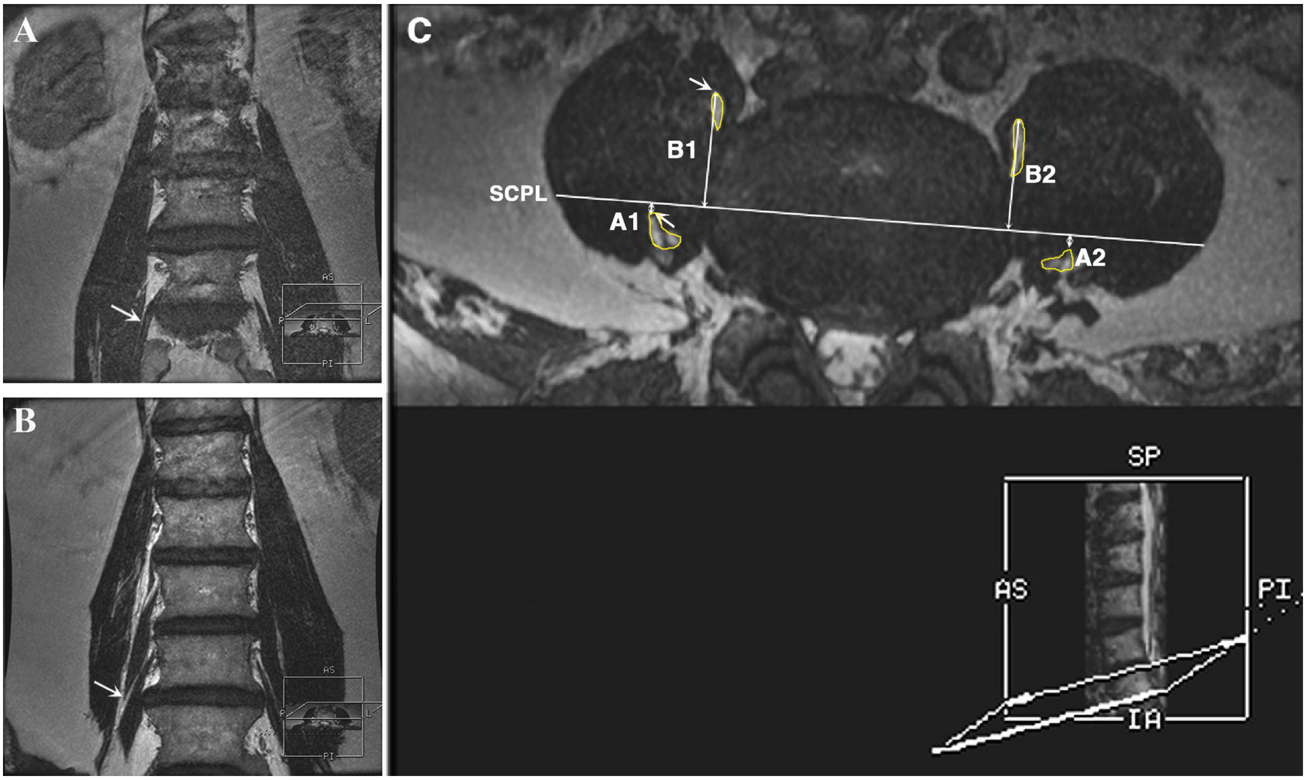

Fig. 3 The measurements at L4–L5 level by coronal image reconstruction. The *arrow* in the original coronal image showed the anterior edge of genitofemoral nerve (**a**) and lumbar plexus (**b**) on the *right side* of the intervertebral space. The *arrow* in the reconstructed axial image (**C**) depicted the anterior edge of lumbar plexus and genitofemoral nerve on the *right side* of the intervertebral space, respectively. The measurements were the same as mentioned above

Table 1 The AID between the anterior edge of lumbar plexus and the SCPL of disc (Mean ± SD, 95 %CI, mm)

	L1–L2	L2–L3	L3–L4	L4–L5
AX	13.33 ± 1.71 (12.83–13.83)	8.76 ± 2.26 (7.79–9.73)	1.30 ± 2.27 (−0.22 to 2.82)	−5.59 ± 3.14 (−7.08 to 4.09)
COR	12.69 ± 1.67 (12.19–13.18)	8.46 ± 2.27 (7.48–9.43)	0.94 ± 2.50 (−0.63 to 2.52)	−5.26 ± 3.41 (−6.82 to 3.70)
Total	13.01 ± 1.70 (12.66–13.36)	8.61 ± 2.26 (7.93–9.29)	1.12 ± 2.37 (0.04–2.21)	−5.42 ± 3.26 (−6.50 to 4.35)

The differences of AID between levels were statistically significant from each other ($P < 0.05$). The differences resulted from two kinds of 3D reconstruction imaging techniques were not statistically significant ($P > 0.05$)

AID the axial image distance, *SCPL* the sagittal central perpendicular line, *AX* axial sequence, *COR* coronal sequence

8.61 ± 2.26,1.12 ± 2.37 and −5.42 ± 3.26 mm from L1–L2 to L4–L5 level (Table 1). Except for the genitofemoral nerve, all the nerve branches were found in zone IV at L4–L5 and above, while they migrated ventrally from zone IV to zone II with respect to intervertebral disc from L1–L2 to L4–L5 level (Table 2).

The differences of AID between levels were statistically significant from each other ($P < 0.05$) (Fig. 4). The differences resulted from two kinds of 3D reconstruction imaging techniques were not statistically significant ($P > 0.05$). The results demonstrated no statistical significance for the weight of the gender factor ($P > 0.05$), even though lumbar plexus of female was measured an average 0.75 mm ventrally positioned than male's (Table 3).

Table 2 Distribution of lumbar plexus (zone)

	L1–L2	L2–L3	L3–L4	L4–L5
The present study	IV	IV	III, IV	II, III, IV
Uribe et al. [8]	IV	IV	IV	III, IV
Guerin et al. [9]	IV	IV	IV	III, IV
Moro et al. [10]	IV	IV	III, IV	III, IV

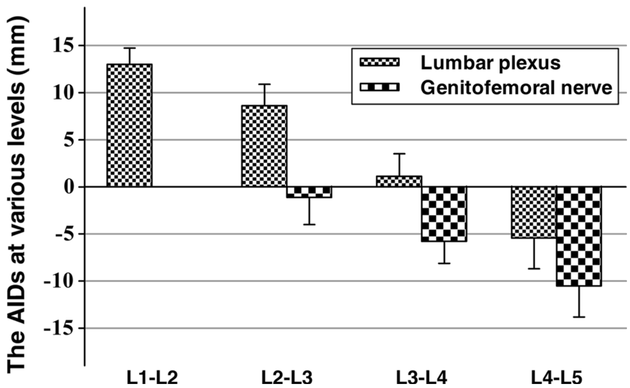

Fig. 4 The diagram about distribution of intrapsoas nerves. The *line* which coincided with *X* axis represented the SCPL of disc. The region *above* the *X* axis suggested that nerves located posteriorly to the SCPL, while *below* it indicated nerves shifting anteriorly to the SCPL. The smaller absolute values of the measurements indicated that intrapsoas nerves lay closer to the SCPL. *AID* the axial image distance, *SCPL* the sagittal central perpendicular line

Position of genitofemoral nerve

Various branches of lumbar plexus which passed through the psoas major anterior to the SCPL of disc were identified in 34 (58.6 %), 46 (79.3 %) and 57 (98.3 %) patients at L2–L3, L3–L4 and L4–L5, respectively. It is possible to infer the presence of genitofemoral nerve in accordance with relevant anatomic research [8–10] (Figs. 2, 3). The AID was −1.13 ± 2.87 mm at L2–L3, −5.78 ± 2.33 mm at L3–L4 and −10.53 ± 3.30 mm at L4–L5 (Table 4). The genitofemoral nerve was identified in zone II at L2–L3, zones I and II at L3–L4 and zone I at L4–L5 accordingly (Table 5).

The differences of AID between levels were statistically significant from each other, which mean a ventral migration of genitofemoral nerve from L2–L3 to L4–L5 level ($P < 0.05$) (Fig. 4). There were no statistically significant differences in results under factors of reconstruction methods and genders ($P > 0.05$).

Interobserver and intraobserver reliability

The average ICC for interobserver reliability was 0.82, while ICC value describing intraobserver reliability was 0.83 and 0.85 for the two viewers, respectively.

Discussion

As is demanded that access point should be located at sagittal radiographic center of the intervertebral disc to establish lateral transpsoas approach, the SCPL of disc in the present study is actually the trajectory of guide wire and axis of access corridor during LLIF. As a result, the relationship between the SCPL of disc and the neural tissue evaluated in this study represents for the relative position between lumbar plexus and access corridor of LLIF approach. When the working channel is established anteriorly to lumbar plexus during sequential dilation of psoas, neural tissues remain relaxed, indicating a low risk of injury to lumbar plexus. On the contrary, the access corridor locating posteriorly to lumbar plexus makes neural tissues in tension and carries the potential risk of injury to the intrapsoas nerves when performing the transpsoas procedure (Fig. 5). If lumbar plexus lies closer to the SCPL of disc, the working channel will be likely to be established posteriorly to lumbar plexus besides occurrence of nerve penetration by guide wire, which increases the risk of nerve injury.

With statistical analysis of the measurements, the present study suggested that lumbar plexus lay posteriorly to the SCPL of disc and away from it at L1–L2 and L2–L3 level, which indicated a low risk of neural retraction. At L3–L4, lumbar plexus located posteriorly to the SCPL of disc but were closer to the SCPL, indicating the possibility of nerve injury due to nerve penetration by guide wire; in addition, sagittal radiographic center of the intervertebral disc is difficult to be located precisely because of operation error. It is inevitable to have slight anterior–posterior misregistration of working channel, which leads to the possibility of working channel being established posteriorly to lumbar plexus. The risk of neural retraction still exists. Lumbar plexus shifted anteriorly to the SCPL of disc at L4–L5 level, not only rendering lumbar plexus at risk of direct nerve penetration, but also increasing significantly the risk of neural retraction, due to the working channel locating posteriorly to lumbar plexus. Coincidentally, the highest incidence of iatrogenic nerve injury has been reported when accessing the L4–L5 level by a number of clinical researches [3, 4]. Owing to obstruction of iliac crest, the LLIF procedure is not suitable to be carried out at

Table 3 The AID between the anterior edge of lumbar plexus and the SCPL of disc with different genders (Mean ± SD, 95 %CI, mm)

	L1–L2	L2–L3	L3–L4	L4–L5
Male	13.16 ± 1.86 (12.58–13.73)	8.97 ± 2.48 (7.87–10.07)	1.52 ± 2.81 (−0.25 to 3.29)	−4.03 ± 3.16 (−6.07 to 1.99)
Female	12.90 ± 1.58 (12.46–13.35)	8.34 ± 2.09 (7.47–9.22)	0.83 ± 2.05 (−0.56 to 2.21)	−5.46 ± 3.34 (−7.55 to 5.37)

There were no significant differences between genders ($P > 0.05$)

AID the axial image distance, *SCPL* the sagittal central perpendicular line

Table 4 The AID between the anterior edge of genitofemoral nerve and the SCPL of disc (Mean ± SD, 95 %CI, mm)

	L2–L3	L3–L4	L4–L5
AX	−0.23 ± 2.39 (−2.60 to 1.10)	−6.61 ± 2.84 (−9.33 to 4.90)	−11.15 ± 3.45 (−13.34 to 8.96)
COR	−1.11 ± 2.32 (−3.20 to 0.99)	−7.97 ± 2.79 (−9.89 to 5.36)	−12.39 ± 3.36 (−14.97 to 9.82)
Total	−1.13 ± 2.87 (−2.32 to 0.06)	−5.78 ± 2.33 (−6.68 to 4.88)	−10.53 ± 3.30 (−11.64 to 9.43)

The differences of AID between levels were statistically significant from each other ($P < 0.05$). The differences resulted from two kinds of 3D reconstruction imaging techniques were not statistically significant ($P > 0.05$)

AID the axial image distance, *SCPL* the sagittal central perpendicular line, *AX* axial sequence, COR coronal sequence

Table 5 Distribution of genitofemoral nerve (zone)

	L2–L3	L3–L4	L4–L5
The present study	II	I, II	I
Uribe et al. [8]	II	I	I
Guerin et al. [9]	II	I, II	I
Moro et al. [10]		I, II	I

L5–S1 level. Measurements at L5–S1 in this study were thus not involved.

In this study, genitofemoral nerve passed through the psoas anteriorly to the SCPL of disc with a ventral migration from L2–L3 to L4–L5 level. As a result, direct neural retraction is likely to take place even if the working channel is moved further anteriorly. Since intraoperative EMG cannot directly identify the signal evoked by sensory nerves, it is unlikely to avoid transient sensory deficits along the region of groin and thigh owing to genitofemoral nerve injury [8, 10, 11].

Distribution of lumbar plexus and genitofemoral nerve in the present study was supported by similar results presented in cadaveric studies with respect to the LLIF approach (Tables 2, 5). Banagan et al. [11] reported that there was no absolute safe zone to allow for the LLIF approach and dissection through the anterior portion of the psoas posed significant risk to the lumbar plexus and genitofemoral nerves especially at L3–L4 and L4–L5 level. Observations in the present MRI study provided the same evidence. In addition, previous MRI researches were limited by locating genitofemoral nerve or other intrapsoas branches of the lumbar plexus and failed to quantify the relative position between lumbar plexus and working channel [12–14].

Dissimilarly, this is the first study to apply 3D reconstruction technology to lumbar plexus imaging with 3D FIESTA sequence of MRI, which allows multiplanar visualization of precise neural structures with satisfactory spatial resolution and without slice gap [7, 15]. It is likely to offset the disadvantages of single two-dimensional images, which fail to identify the continuous full view of the lumbar nerve root from foraminal to extraforaminal [7]. AID calculated by way of point coordinates and the distance formula is much more accurate than traditional measurements. The differences of AID resulted from distinct 3D reconstruction imaging techniques were not

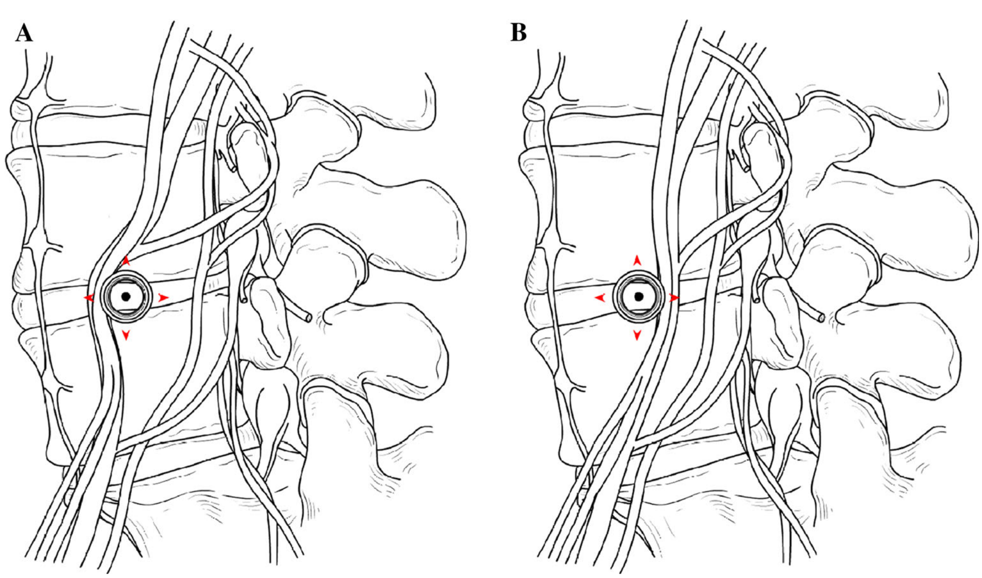

Fig. 5 The diagram of relative position between working channel and lumbar plexus at L4–L5 level. With respect to the working channel, when locating posteriorly to lumbar plexus makes neural tissues in tension and carries the potential risk of neural retraction (**a**), while established anteriorly to lumbar plexus enables neural tissues to remain relaxed indicating a low risk of injury to lumbar plexus (**b**)

statistically significant ($P > 0.05$), reflecting superiority of 3D FIESTA sequence for lumbar plexus imaging. The ICC values for inter- and intraobserver reliability in this study indicated good reliability based on the semiquantitative criteria described below [14]: excellent for a value of 0.90–1.00, good for 0.70–0.89, fair/moderate for 0.50–0.69, low for 0.25–0.49, and poor for 0.00–0.24, which further verified the accuracy and reproducibility of the present study.

In consideration of the results obtained in this study, preoperative view of the magnetic resonance neural imaging distribution of lumbar plexus is likely to reduce the incidence of neurological complications as related to LLIF. It is reported that intraoperative guidance of fluoroscopy and EMG neuromonitoring is critical, which helps to reduce the complication rate of nerve injury [1, 5, 16]. Meanwhile, the AID can be used as a reference value for establishment of working channel during LLIF. Due to the individual differences, it is suggested that the initial access point and dilator trajectory should be established in accordance with the individual measurements preoperatively. Generally, with the purpose of lessening the nerve strain and the risk of neural retraction, the access point can be located at sagittal radiographic center of the intervertebral disc at L1–L2 and L2–L3 level even without the aid of EMG. However, it calls for an anterior migration of the initial access point and dilator trajectory subsequently at L3–L4 and L4–L5 level. Besides, there is a necessity for surgeons to minimize the radius of expandable retractor as much as possible and shorten the operation time.

Since MRI is unlikely to be performed with patients in lateral decubitus position, it is difficult to estimate the impact of surgical position on the measurements. There is a certain degree of measurement errors owing to limited ability of neural imaging and identification. Although the 3D reconstruction imaging technique is capable to show us intrapsoas nerves, it is still incapable of accurately identifying every branch of lumbar plexus. The nerve fibers of genitofemoral nerve in this study become increasingly apparent from L2–L3 to L4–L5, resulting in an increasing identification rate. The present study did not rule out patient's individual differences such as height, weight and age, which may affect the distribution of lumbar plexus. Additionally, the measurements may not apply to patients with scoliosis, requiring subsequent researches on larger scales.

In conclusion, with respect to the SCPL of disc, a radiographic reference landmark to place working channel, lumbar plexus lies posteriorly to it from L1–L2 to L3–L4 level and shifts anteriorly to it at L4–L5 level, while genitofemoral nerve locates anteriorly to the SCPL from L2–L3 to L4–L5 level. Ventral migration of intrapsoas nerves is identified from L1–L2 to L4–L5 level. There is a higher risk of neural retraction during sequential dilation of working channel at L4–L5 level.

Acknowledgments This work was supported by the Special Project on the Integration of Industry, Education and Research of Guangdong Province, China 2011B090400078. The authors would like to thank Dr. Rui-Qiang Chen, Dr. Pei-Gen Xie, Dr. Liang-Ming Zhang, Dr. Jian-Wen Dong, Dr. Bin Liu, Dr. Feng Feng, Dr. Bu Yang, Dr. Mao Pang and Dr. Yang Yang from Department of Spine Surgery, Third Affiliated Hospital, Sun Yat-sen, for their help in conducting this study and overseeing the project.

Conflict of interest The authors declare no conflict of interest.

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