Safety margin for needle placement during lumbar plexus block: An anatomical study using magnetic resonance imaging

Marge de sécurité pour le positionnement de l'aiguille au cours d'un bloc lombaire : étude anatomique avec imagerie par résonance magnétique

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Abstract

Purpose We aimed to provide anatomic characteristics of the lumbar plexus and a safety margin for needle placement during lumbar plexus block in adults.

Methods Lumbar spine magnetic resonance images from 377 adults were reviewed. We determined the depth of the lumbar plexus from the needle insertion point for the modified traditional and Capdevila's approaches at the L4 and L5 levels. The relationship of age, height, and body weight with lumbar plexus depth, and the presence of the kidney on the transverse plane at the L4 level were assessed.

Results The lumbar plexus was deeper at the L5 level than at the L4 level for both approaches (mean difference 3.2 mm [95% confidence interval (CI), 2.4 to 4.0] for the modified traditional approach; mean difference 4.4 mm [95% CI, 3.7 to 5.2] for Capdevila's approach). Eighty-six (22.8%) patients had an L4 transverse process shorter than 40 mm, which implies that the needle may not contact the L4 transverse process with the modified traditional approach. The mean (standard deviation) of safety margins for needle insertion, defined as the distance from the posterior aspect of the L4 transverse process to the

anterior margin of the psoas muscle, were 45 (8) and 44 (6) mm, respectively for the modified traditional and Capdevila's approach (mean difference, 0.5 mm; 95% CI, −0.1 to 1.1). The lumbar plexus depth for each approach at the L4 level was predicted using the following equations: $\text{Depth (mm)} = 87.24 - 0.36 \times \text{height (cm)} + 0.69 \times \text{weight (kg)}$ for the modified traditional approach ($r^2 = 0.37$) and $\text{Depth (mm)} = 86.51 - 0.35 \times \text{height (cm)} + 0.61 \times \text{weight (kg)}$ for Capdevila's approach ($r^2 = 0.33$). The kidney was observed at the L4 level in 60 (15.9%) patients, with higher incidence in patients over 70 yr and those shorter than 150 cm.

Conclusion The surface anatomic relations of the lumbar plexus found in this study may be useful for performing successful and safe lumbar plexus block.

Résumé

Objectif Nous avons cherché à fournir des données anatomiques du plexus lombaire et de la marge de sécurité pour le positionnement de l'aiguille au cours d'un bloc lombaire chez l'adulte.

Méthodes Les images par résonance magnétique de la colonne vertébrale lombaire de 377 adultes ont été analysées. Nous avons déterminé la profondeur du plexus lombaire à partir du point d'insertion de l'aiguille pour les approches traditionnelle modifiée et de Capdevila aux niveaux L4 et L5. Les corrélations de l'âge, de la taille et du poids corporel avec la profondeur du plexus lombaire et la présence du rein sur le plan de l'apophyse transverse au niveau de L4 ont été évaluées.

Résultats Le plexus lombaire était plus profond à l'étage L5 qu'à l'étage L4 pour les deux approches (différence moyenne : 3,2 mm [intervalle de confiance

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(IC) à 95 % : 2,4 à 4,0] pour l'approche traditionnelle modifiée; différence moyenne : 4,4 mm [IC à 95 % : 3,7 à 5,2] pour l'approche de Capdevila). Quatre-vingt-six patients (22,8 %) avaient l'apophyse transverse de L4 mesurant moins de 40 mm, ce qui implique que l'aiguille pourrait ne pas faire contact avec cette apophyse avec l'approche traditionnelle modifiée. Les marges de sécurité pour l'insertion de l'aiguille, définies comme étant la distance moyenne (écart-type) entre la face postérieure de l'apophyse transverse de L4 et la marge antérieure du muscle psoas, étaient de 45 (8) mm et 44 (6) mm pour, respectivement, l'approche traditionnelle modifiée et l'approche de Capdevila (différence des moyennes, 0,5 mm; IC à 95 % : -0,1 à 1,1). La profondeur du plexus lombaire pour chaque approche au niveau L4 a été prédite à l'aide des équations suivantes : Profondeur (mm) = $87,24 - 0,36 \times \text{taille (cm)} + 0,69 \times \text{poids (kg)}$ pour l'approche traditionnelle modifiée ($r^2 = 0,37$) et Profondeur (mm) = $86,51 - 0,35 \times \text{taille (cm)} + 0,61 \times \text{poids (kg)}$ pour l'approche de Capdevila ($r^2 = 0,33$). Le rein a été observé au niveau L4 chez 60 patients (15,9 %) avec une plus grande incidence chez les patients âgés de plus de 70 ans et chez ceux dont la taille était inférieure à 150 cm.

Conclusion Les rapports anatomiques de la surface du corps et du plexus lombaire identifiés dans cette étude peuvent contribuer à la réalisation d'un bloc lombaire efficace et sécuritaire.

Lumbar plexus block (LPB) is an effective anesthetic and analgesic technique for lower limb surgery. The lumbar plexus is composed of the first four lumbar roots and descends through the psoas muscle in the retroperitoneal cavity. Because of the deep location of the lumbar plexus, LPB carries a risk of several serious complications including epidural spread of local anesthetics, inadvertent neuraxial anesthesia, local anesthetic systemic toxicity, and retroperitoneal hematoma.¹⁻⁶ To avoid such complications, an accurate anatomical knowledge of the lumbar plexus is essential.

In recent years, several authors have described LPB techniques under ultrasound guidance, which have been widely used in patients undergoing lower limb surgery.⁷⁻¹⁰ Despite numerous advantages, including real-time guidance and safety, the ultrasound-guided nerve blocks need specialized equipment and an adequate level of expertise. In addition, the procedure is more complicated in patients with obesity. Therefore, it is important to know the precise anatomical location of the lumbar plexus for

successful LPB, regardless of whether ultrasound guidance is used.

There are various approaches for landmark-guided LPB. With the modified traditional approach, the needle entry point is 4 cm lateral to the spinous process at the level of the L4 vertebral body.¹ Capdevila *et al.* showed an alternative approach, based on computed tomography (CT), in which the needle is inserted at the junction of the lateral third and medial two thirds of a line drawn between the midline and a vertical line passing through the posterior superior iliac spine (PSIS).¹¹ These approaches may have differences in lumbar plexus depth and clinical considerations for successful block without complications.

Depth of the lumbar plexus was measured using cadavers, CT, or ultrasound images in previous studies.¹²⁻¹⁴ Nevertheless, sample sizes were too small to generalize the anatomical information. Magnetic resonance imaging (MRI) can differentiate paravertebral soft tissues better than CT images because of high contrast between normal fat and other tissues. Hence, MRI can locate the lumbar plexus more precisely. The purpose of this study was to assess the anatomy of the lumbar plexus and to provide a safety margin for needle insertion during LPB in adults using MRI data.

Methods

Ethical approval for this study (no. 1707-148-872) was granted by the institutional review board of Seoul National University Hospital, Seoul, Korea on July 2017. We retrieved lumbar spine MRI scans of adult (aged 19 yr and above) patients between January 2013 and December 2016 from the Picture Archiving and Communication System of the Seoul National University Hospital. We excluded patients with unknown height or body weight at the time of scanning, or paravertebral lesions resulting in anatomical distortion. Informed consent was waived by the institutional review board considering the retrospective design of the study using an electronic database.

Magnetic resonance imaging parameters

MRI scans were performed using one of seven scanners (Signa HDxt 1.5T, Excite 1.5T, Discovery MR750w 3.0T, MAGNETOM Avanto 1.5T, Ingenia 3.0T, Skyra 3.0T, Sonata 1.5T, or Verio 3.0T) made by one of three manufacturers (GE Healthcare, Chicago, IL, USA; Siemens Healthineers, Erlangen, Germany; or Philips, Amsterdam, The Netherlands). All imaging protocols included a sagittal T1-weighted fast spin-echo sequence, a sagittal and an axial T2-weighted fast spin-echo

Figure Measurements of lumbar spine magnetic resonance images. (a) and (b) indicate the imaginary needle pathway for Capdevila's and the modified traditional approaches, respectively. D1 = distance from midline to PSIS; D2 = 2/3 of D1; LP = lumbar plexus; PM = psoas muscle; PSIS = posterior superior iliac spine; TP = transverse process

sequence. MRI scans were taken in a supine position for all patients.

The Figure shows axial T2-weighted images illustrating the anatomical measurements we performed. Although LPB is usually performed at the L4 vertebral level in both approaches, we measured each variable at both L4 and L5 levels because the lumbar vertebral level is often incorrectly identified by palpation.¹⁵ After identification of the transverse processes of L4 and L5 vertebrae, depth of the lumbar plexus, the posterior aspect of the transverse process, and the anterior aspect of the psoas muscle from the skin were measured at 4 cm lateral to the midline (the

modified traditional approach),¹ and at the junction of the lateral third and medial two thirds of a line drawn between the midline and the vertical line passing through the PSIS (Capdevila's approach).¹¹ The midline was defined as a straight line along the midpoint of the dural sac and spinous processes. The length of the transverse process from the midline was also measured at each vertebral level.

Given that the depth of the needle can be estimated by contact to the transverse process during LPB,¹⁶ we calculated the distance from the posterior aspect of the transverse process to the lumbar plexus. In addition, we defined a safety margin for needle advancement as the distance between the posterior aspect of the transverse process and the anterior aspect of the psoas muscle. All measurements were performed parallel or perpendicular to the midline (Figure). Visualizations of the lower pole of the kidney at the L4 level were also recorded.

Statistical analysis

Numerical variables are presented as mean (standard deviation [SD]), while categorical variables are presented as number of patients (percentage). The differences in anatomical measurements according to approach and sex were evaluated using 95% confidence interval (CI) values. A linear regression model was constructed to evaluate the correlation of variables including age, height, and body weight with the lumbar plexus depth. We used a backward stepwise multiple linear regression analysis to predict depth of the lumbar plexus, the posterior aspect of the transverse process, and the anterior aspect of the psoas muscle using variables including age, height, and body weight. A backward stepwise logistic regression analysis was used for assessing the influence of age, sex, height, and body weight on visualization of the lower pole of the kidney at the L4 level. All analyses were performed using R software version 3.4.3 (R Foundation for Statistical Computing, Vienna, Austria), and $P < 0.05$ was considered statistically significant.

Results

A total of 807 MRI scans were acquired from adult patients between January 2013 and December 2016. Among them, 311 MRI scans were excluded because of unknown height or body weight at the time of scanning. A further 119 scans were also excluded due to repeated scans of the same patient (27 scans), instrumentation (26 scans), severe compression fracture (23 scans), poor image quality (21 scans), severe scoliosis (eight scans), paravertebral mass (eight scans), and severe spondylosis (six scans). The remaining 377 MRI scans were included in the final

Table 1 Anatomical measurements (mm) of the lumbar plexus according to vertebral level

	L4	L5	Mean difference	95% CI
Modified traditional approach				
Depth of LP	71 (11)	74 (11)	3.2	2.4 to 4.0
Depth of TP	54 (10)	57 (10)	3.7	3.0 to 4.3
Depth of anterior aspect of PM	98 (13)	105 (13)	7.0	6.2 to 7.7
TP-LP distance	17 (5)	17 (5)	−0.4	−1.1 to 0.3
TP-anterior aspect of PM distance	45 (8)	48 (8)	3.6	2.9 to 4.3
Capdevila's approach				
Depth of LP	67 (10)	72 (11)	4.4	3.7 to 5.2
Depth of TP	55 (10)	56 (11)	1.1	0.4 to 1.8
Depth of anterior aspect of PM	99 (12)	101 (12)	1.5	0.8 to 2.2
TP-LP distance	12 (5)	15 (5)	3.3	2.6 to 4.1
TP-anterior aspect of PM distance	44 (6)	44 (8)	0.4	−0.3 to 1.1
Length of TP	43 (4)	46 (4)	3.5	3.1 to 3.9

Data are presented as mean (standard deviation)

CI = confidence interval; LP = lumbar plexus; PM = psoas muscle; TP = transverse process

analysis. The mean (SD) patient characteristics were as follows: age 65 (16) yr; height 160 (10) cm; weight 61 (12) kg; and body mass index 23.8 (3.6) kg·m^{−2}.

Table 1 summarizes the anatomical measurements according to vertebral level. The depth of the lumbar plexus for both approaches at the L4 level were less than those at the L5 level (Table 1). The mean lumbar plexus depth with Capdevila's approach was lower than with the modified traditional approach at the L4 (mean difference, 3.9 mm; 95% CI, 3.4 to 4.4) and the L5 level (mean difference, 2.3 mm; 95% CI, 1.8 to 2.9). The safety margin for needle advancement was wider at the L5 level than the L4 level for the modified traditional approach, but for Capdevila's approach there was no difference between the two levels (Table 1). There was no difference in safety margin for needle advancement at the L4 level between the two approaches (mean difference, 0.5 mm; 95% CI, −0.1 to 1.1), while the safety margin for the modified traditional approach was wider than that for Capdevila's approach at the L5 level (mean difference, 3.5 mm; 95% CI, 2.8 to 4.1).

The L5 transverse process was longer (mean difference, 3.4 mm; 95% CI, 2.9 to 3.9) than the L4 transverse process (Table 1). The L4 transverse process was shorter than 40 mm (the distance from the midline to the needle insertion point with the modified traditional approach) in 86/377 (22.8%) patients, while the L5 transverse process was shorter than 40 mm in only 14 (3.7%) patients.

The anatomical measurements according to sex are presented in eTable 1 (available as Electronic Supplementary Material [ESM]). There was no difference in the depth of the lumbar plexus and the depth of the transverse process between male and female patients.

Nevertheless, the depth of the anterior aspect of the psoas muscle from the skin was greater in male than in female patients (available as ESM, eTable 1).

Table 2 shows the results from multiple linear regression analyses to predict depth of the lumbar plexus, the posterior aspect of the transverse process, and the anterior aspect of the psoas muscle using age, height, and body weight according to vertebral level and type of approach. Simple linear regression analysis revealed that body weight correlated most with the lumbar plexus depth, with deeper location in patients with a higher body weight (available as ESM, eFigure). The depth of the lumbar plexus and that of the anterior aspect of the psoas muscle with both approaches according to subgroups of body weight (< 50 kg, 50–70 kg, and > 70 kg) are shown in ESM eTable 2.

The lower pole of the kidney was seen at the L4 level in 60 (15.9%) patients. In patients shorter than 150 cm, the kidney was visualized at the L4 level more frequently (17/53; 32.1%) compared with those over 150 cm tall (43/324; 13.3%; $P = 0.001$). Similarly, patients older than 70 yr had a more inferiorly located kidney (40/176; 22.7%) compared with those less than 70 yr old (20/201; 10.0%; $P = 0.001$). After adjusting, both age and height still had a significant impact on whether the lower pole of the kidney was seen at the L4 level (Table 3).

Discussion

In this study, we presented the surface anatomic relations of the lumbar plexus and proposed a safety margin for

Table 2 Linear regression models for depth (mm) of the lumbar plexus, the transverse process, and anterior aspect of the psoas muscle according to vertebral level and approach technique

		L4		L5	
		Equation	r^2	Equation	r^2
Modified traditional approach	Depth of LP	$87.24 - 0.36 \times \text{height} + 0.69 \times \text{weight}$	0.37	$97.66 - 0.41 \times \text{height} + 0.69 \times \text{weight}$	0.37
	Depth of TP	$58.91 - 0.28 \times \text{height} + 0.63 \times \text{weight}$	0.36	$66.04 - 0.31 \times \text{height} + 0.67 \times \text{weight}$	0.40
	Depth of anterior aspect of PM	$64.55 - 0.13 \times \text{height} + 0.89 \times \text{weight}$	0.56	$77.18 - 0.18 \times \text{height} + 0.92 \times \text{weight}$	0.59
Capdevila's approach	Depth of LP	$86.51 - 0.35 \times \text{height} + 0.61 \times \text{weight}$	0.33	$68.64 - 0.24 \times \text{height} + 0.68 \times \text{weight}$	0.39
	Depth of TP	$64.77 - 0.29 \times \text{height} + 0.60 \times \text{weight}$	0.35	$75.98 - 0.39 \times \text{height} + 0.69 \times \text{weight}$	0.39
	Depth of anterior aspect of PM	$70.19 - 0.10 \times \text{height} + 0.74 \times \text{weight}$	0.51	$70.59 - 0.11 \times \text{height} + 0.77 \times \text{weight}$	0.50

Depth of each structure are in mm, height and weight are in cm and kg, respectively

Age was excluded by a backward stepwise method in all models

LP = lumbar plexus; PM = psoas muscle; TP = transverse process

Table 3 Factors affecting on visualization of the lower pole of the kidney at the L4 level

	Unadjusted			Adjusted		
	Odds ratio	95% CI	<i>P</i>	Odds ratio	95% CI	<i>P</i>
Age $\geq$ 70 yr	2.66	1.51 to 4.84	0.001	2.04	1.11 to 3.80	0.023
Male	0.61	0.34 to 1.07	0.089	-	-	-
Height $\leq$ 150 cm	3.09	1.57 to 5.92	< 0.001	2.15	1.06 to 4.25	0.031
Weight $\geq$ 70 kg	0.31	0.10 to 0.73	0.016	0.44	0.15 to 1.07	0.098

CI = confidence interval

needle placement during LPB according to vertebral level and type of approach. We also found that the depth of the lumbar plexus significantly correlated with body weight; patients older than 70 yr or those shorter than 150 cm were at higher risk of accidental renal puncture with LPB at the L4 level.

When performing LPB without ultrasound guidance, needle contact with the transverse process is an important step in determining the depth of the lumbar plexus.¹⁶ Previous studies have shown that the lumbar plexus is generally located within the psoas major muscle, rather than posterior to it.^{11,17} Consequently, once the needle encounters the transverse process, it should be assumed that the lumbar plexus is located within approximately 1-2 cm, and the safety margin of needle insertion, determined by the depth to the anterior aspect of the psoas muscle, is approximately 4-5 cm to avoid retroperitoneal puncture. Additional techniques including nerve stimulation can improve the safety and accuracy of LPB.¹⁸

According to our results, the needle insertion point with the modified traditional approach was too lateral to reach the lumbar plexus. A cadaver study demonstrated that although the needle insertion point with Capdevila's approach was 6 mm lateral to the lumbar plexus, it was the most reliable of the traditional methods.¹⁹ The results

of our study also corroborate with the reliability of the method described by Capdevila. Given that the L4 transverse process was shorter than 4 cm in over 20% of subjects, the needle may not contact the transverse process with the modified traditional approach. Although the safety margin for needle insertion was similar at the L4 level with the two approaches, Capdevila's approach seems to be the more favorable method for lumbar plexus block at the L4 level compared with the modified traditional approach because the L4 transverse process being shorter than 40 mm was not rare.

At the L5 level, on the other hand, the anatomical considerations for assessing the reliability of the two approaches are slightly different. In contrast to the L4 level, the safety margin for needle insertion in the modified traditional approach was wider than that in Capdevila's approach at the L5 level. In addition, the probability of the transverse process being shorter than 40 mm was lower at the L5 level than at the L4 level. The approach technique and procedural level should be selected after considering advantages and disadvantages with regard to anatomical features.

Considering the course of the lumbar plexus arising from each intervertebral foramen and descending within the psoas muscle, it is obvious that the lumbar plexus has a

more anterolateral position at the L5 than at the L4 level. Meanwhile, the depth of the lumbar plexus did not differ between male and female subjects according to our data. The distance to the anterior aspect of the psoas muscle from the skin was greater in male than in female subjects; this difference is due to a larger muscle mass in male compared with female subjects. This means that the safety margin for needle advancement after contact with the transverse process may be less in females.

A strong correlation between body weight and the lumbar plexus depth was noted at both levels. The safety margin was also significantly associated with body weight. Although equations predicting depth of the lumbar plexus, the transverse process, and the anterior aspect of the psoas muscle were produced by multiple regression analyses, we also complemented the depth of the lumbar plexus according to body weight strata in eTable 2 (available as ESM) that could be clinically relevant during LPB.

Although Parkinson *et al.* demonstrated that there was no statistical difference in the extent of neural blockade between the L4-L5 and the L3 approach,²⁰ the L4 or L5 level has been recommended for LPB to avoid renal injury in previous studies.^{5,14} Nevertheless, the lower pole of the kidney was visualized at the L4 level in more than 15% of participants in our study. We also found that the risk of renal puncture is higher in patients older than 70 yr or shorter than 150 cm. As a blind LPB tends to pose the risk of renal puncture, physicians should be careful when performing LPB without ultrasound guidance at the L4 level, especially in patients who are older or shorter.

The depth of the lumbar plexus measured in this study was lower than previously estimated, defined as the junction of the posterior third and the anterior two thirds of the psoas muscle.¹² A possible explanation is that our study was conducted on Asian populations, and perhaps in less obese subjects because body weight correlated significantly with the lumbar plexus depth, even though demographic data were not available. This could also explain why the lumbar plexus was located deeper in cadaver studies, similar in age but not in body weight to our patients.^{11,19} On the contrary, a study that evaluated paravertebral anatomy using ultrasound images demonstrated a shorter distance from the skin to the lumbar plexus than our study.¹⁴ This discrepancy could be due to the effect of compression by the ultrasound probe for image optimization. Indeed, there was a difference of 0.5 cm between the predicted depth of the transverse process by ultrasound and the actual depth.²¹ We studied images from MRI scans acquired in the supine position, which are likely to reveal actual rather than predicted depths of the lumbar plexus.

Our study has several limitations. First, we did not obtain data from healthy volunteers; our measurements

were taken from patients who underwent lumbar MRI. Hence, our results may not be representative of the general population. To overcome potential selection bias, we excluded patients with paravertebral lesions causing anatomical distortion, including instrumentation, mass, spondylosis, or kyphosis. Second, although we regressed age against the lumbar plexus depth, the age distribution of participants was negatively skewed. Third, although we produced equations predicting depth of the lumbar plexus using multiple regression analyses, these models had relatively low correlation coefficients and were not validated. To compensate for these weaknesses, we presented the depth of the lumbar plexus and anterior aspect of the psoas muscle in eTable 2 (available as ESM) by dividing patients according to body weight, which correlates best with the depth of the lumbar plexus. Fourth, all MRI scans were obtained in the supine position, which is different to the lateral decubitus position in which LPB is usually performed. In addition, various MRI machines with different magnetic field strengths could affect spatial resolution and possibly the measurement values. Lastly, the plane of the MRI images may not always be exactly perpendicular to the spinal axis, which may result in underestimation or overestimation of distances from the midline to each point of measurement.

The surface anatomic relations of the lumbar plexus provided in this study may help to avoid complications such as neuraxial blockade, retroperitoneal injection, and renal puncture. Although various approaches of ultrasound-guided LPB have emerged in recent years, it is clinically significant to consider the anatomy of the lumbar plexus, including the actual depth of the lumbar plexus, the distance from the posterior aspect of the transverse process to the lumbar plexus, and the safety margin for needle insertion for LPB. The potential risk of renal injury should be considered in elderly or short patients who tend to have an inferiorly located kidney when performing LPB at the L4 level.

Conflicts of interest None declared.

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Author contributions Seokha Yoo contributed substantially to the study design, data acquisition, data analysis, and writing the manuscript. Sheung-Nyoung Choi contributed substantially to data acquisition and revising the manuscript. Sun-Kyung Park contributed substantially to data acquisition and writing the manuscript. Won Ho Kim contributed substantially to the study design and data analysis. Young-Jin Lim contributed substantially to the study conception and revising the manuscript. Jin-Tae Kim contributed substantially to the study conception, study design, data analysis, and revising the manuscript.

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