Flexion-rotation manoeuvre increases dimension of the acoustic target window for paramedian thoracic epidural access

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Editor’s key points

- The best patient position for identifying the thoracic epidural space is debated.
- This volunteer study used ultrasound to visualize the posterior longitudinal ligament and hence identify the thoracic epidural space.
- Using 10° dorsal table tilt and flexion with right rotation via a paramedian approach improved the acoustic target area.
- This position may facilitate epidural catheter placement but further studies are needed.

Background. The posterior longitudinal ligament (PLL) has been found to be a reliable measure of the acoustic target window for lumbar spinal anaesthesia and a predictive tool for difficult spinals. Currently, there is limited information on the PLL in the thoracic spine and its potential use for optimizing the acoustic target window during thoracic epidural placement. This study examined the effects of changes in body position on the length of the PLL as a measure of the acoustic target window for paramedian thoracic epidural access.

Methods. We performed thoracic ultrasonography on 30 adult volunteers to measure the length of the PLL at the T9/10 interspace, in five different positions: P1, neutral; P2, thoracic and lumbar flexion; P3, as in position 2 with dorsal table tilt to 10°; P4, as in position 2 with 45° rightward shoulder rotation; and P5, as in position 2 with 45° leftward shoulder rotation.

Results. The mean (sd) PLL length increased significantly from 9.9 (3.9) mm in P1 to 11.7 (3.4) mm in P2, 12.9 (3.1) mm in P3, and 13.8 (4.0) mm in P4 (P<0.01, <0.01, and <0.01, respectively). The mean PLL length in P3 and P4 was also significantly longer compared with P2 (P<0.01 and 0.01, respectively).

Conclusions. In volunteers, flexion with 10° dorsal table tilt and flexion with right rotation significantly increased the length of the ipsilateral PLL, compared with the standard flexed sitting position, as visualized by paramedian ultrasonography at the level of T9/10.

Keywords: anaesthetic techniques, epidural; monitoring, ultrasound

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acceptable degree of precision in the depiction of structures. This approach overcomes the steep angulation of overlapping spinous processes and narrow intervertebral spaces, compared with a midline approach. Although changes in the dimensions of the interspinous space and ligamentum flavum, as measured by ultrasonography, are proposed to be important factors in determining successful midline neuraxial needle insertion in the lumbar region, they have limited utility in the thoracic region because the ligamentum flavum is thin in the thoracic region and there is acoustic interference from the steeply angled spinous processes.

In addition, the posterior complex (ligamentum flavum, epidural space, and posterior dura) is not consistently visible so that its dimensions cannot be utilized as a guide to the width of the interlaminar window. In previous descriptions of ultrasound-guided neuraxial techniques, the importance of sonographic visualization of the PLL as a guidance structure for neuraxial puncture has been emphasized, because even though the PLL is part of the anterior aspect of the epidural space, clear visualization of the PLL is indicative of an ‘open acoustic window’, with an unobstructed path to the dura between the laminae, and may provide indication of the technical difficulty associated with neuraxial access.

The posterior longitudinal ligament (PLL) can be easily visualized in the thoracic region via a paramedian view. The posterior longitudinal paramedian plane was used to achieve optimal access. The posterior longitudinal plane can be identified by the ‘sawtooth’ ultrasound pattern and the ligamentum flavum/posterior dura visualized as a bright hyperechoic line. The PLL and posterior vertebral body were visualized as a deeper hyperechoic structure and identified in all images.

Methods

This study was approved by the Clinical Research Ethics Board of the University of British Columbia on September 14, 2012, and registered with the Office of Research Services of the University of British Columbia (H12-02141). Informed written consent was obtained from 30 healthy volunteer subjects recruited at Vancouver General Hospital. Inclusion criteria were the ability to achieve the five positions expected in the study and to provide written informed consent. We excluded volunteers with a history of spinal trauma, spinal surgery, or congenital spinal abnormality and allergy to ultrasound gel. Age, weight, height, and BMI were recorded for each participant.

All volunteers were sitting on a height-adjustable operating theatre table with feet fully supported, to bend the hips and knees to 90°. Spinal ultrasonography was performed in five study positions (Figs 1 and 2):

P1. Neutral: no back flexion/extension.

P2. Flexion: slouching of the shoulders with lumbar flexion and exaggeration of the thoracic kyphosis with arms around a pillow at chest level.

P3. Table tilt: as in position 2 and dorsal table tilt to 10°.

P4. Right rotation: as in position 2 and 45° rightward shoulder rotation.

P5. Left rotation: as in position 2 and 45° leftward shoulder rotation.

Table tilt angle was limited to 10° because 15° was not tolerated by patients in a previous study. Table tilt was measured using the Tiltmeter application (Integrasoft, Bridgewater, NJ, USA) on an iPhone 3G (Apple, Cupertino, CA, USA) and confirmed using a protractor with a hanging weight.

Using a 2–5 MHz curvilinear transducer (Ultrasonix, Richmond, BC, Canada), the T9/10 intervertebral level was identified, by scanning in a longitudinal paramedian plane from the sacral plate and moving cranially counting each lamina. Secondary confirmation of the level was performed by manual palpation of the spinous processes from the level of the sacral plate.

We chose to study the T9/10 level because an epidural catheter at this level has the potential of providing dermatomal analgesia for most thoracic and abdominal procedures and is the level most often used in our centre. A right longitudinal paramedian plane was used to achieve optimal images.

The laminae were identified by the ‘sawtooth’ ultrasound pattern and the ligamentum flavum/posterior dura visualized as a bright hyperechoic line. The PLL and posterior vertebral body were visualized as a deeper hyperechoic structure and identified in all images.

Two experienced fellows (N.R., J.W.) in anaesthesiology (>50 neuraxial ultrasound scans) performed the scans and measurements but could not be blinded to patient position. The first anaesthesiologist (N.R.) performed all the ultrasound scans and the second anaesthesiologist (J.W.) measured and recorded the length of the most superficial and inferior aspects of the PLL using the onscreen caliper tool. The first anaesthesiologist was blinded to the actual distances measured. The process of scanning and measurement was repeated in the same sequence for each of the five study positions in all subjects. The entire scans were recorded as a video file and re-measured by a third anaesthesiologist (R.T.), blinded to the patient positions and blinded to PLL measurements made by the second anaesthesiologist (J.W.). This second data set of PLL measurements was used to quantify inter-observer agreement.

Sample size was estimated based on data from a comparable study using a 1 mm change in target area dimensions, a 1 mm SD, an α of 0.05, and a power of 90% to yield a sample size of 16 subjects. Since an epidural needle is ~1 mm in diameter, any increase in target area dimensions of 1 mm can be theoretically important in determining successful access to the epidural space. After statistical consultation, we estimated a sample size of 30 volunteers would be adequate to show significant change in the mean length of the PLL (acoustic target area) in any of the five positions. The data were analysed using repeated-measures analysis of variance, in pairwise comparisons for measurements of the mean PLL length in each of the positions (with the Bonferroni adjustment to maintain P<0.05). Tests of normality were performed...
with the Kolmogorov–Smirnov (Lilliefors’ significance correction) and the Shapiro–Wilk checks. Intraclass coefficients (one-way random effects model) were used to evaluate the reliability and repeatability of the PLL measurements performed by the two different anaesthesiologists. All data analyses were conducted using Statistical Package for the Social Sciences (SPSS) software (Version 20.0), IBM Corporation, Armonk, NY, USA.

Fig 1 With the subjects seated in the standard flexed position with legs supported and cradling a pillow, they were asked to rotate their shoulders to a 45° angle (a). The spine is shown in the rotated position (a) with the inset depicting the effect on the T9/10 vertebrae. The original position of the vertebrae is shown with the grey shadow. Spine flexion separates the spinous processes and rotation further opens up the interlaminar space by causing the T9 spinous process to move away from the T10 lamina. This potentially increases the target area for epidural placement.
Results

Thirty volunteers participated; of which, 20 were males and 10 females. The mean (SD) age was 39.4 (10.1) yr; BMI was 24 (3.8) kg m$^{-2}$, with the mean height and weight being 174 (9.8) cm and 72.9 (3.8) kg, respectively.

In all eligible cases, the epidural space at T9–10 was easily identified on ultrasonography and the quality of ultrasound images was comparable with previous studies\textsuperscript{4, 7–9}. The characteristic acoustic shadow was seen anterior to the laminae corresponding to that of T9 and T10. The ligamentum flavum was seen as a hyperechoic structure and deeper to it was the hyperechoic PLL. The quality of the PLL images (Fig. 3) was good (Weed score >9).\textsuperscript{4} The superior and inferior limits of the PLL were sufficiently and clearly demarcated on the images to enable precise measurement of length with the onscreen caliper tool.

In all subjects, all images were successfully saved and archived, and there was no loss of data during screen capture mode, measurement mode, and archive retrieval mode. There was a progressive and significant increase in the length of the PLL in positions 2, 3, and 4 when compared with the neutral position 1, as shown in Table 1. In comparison with the standard flexed position for epidural insertion (P2), a 10$^\circ$ table tilt in addition to flexion (P3) and rotation (ipsilateral to the transducer) with flexion (P4) significantly increased the length of the visualized PLL (Table 1). Rotation (contralateral to the transducer) with flexion (P5) did significantly change the PLL length compared with position 1 but not compared with position 2. The correlation coefficient for measurement of the PLL length by the two independent anaesthesiologists was 0.612 ($P<0.05$).

Discussion

In this study, we measured the length of the PLL with ultrasonography to estimate the size of the interlaminar ‘acoustic target window’ for thoracic (T9–10) paramedian epidural access. We demonstrated that compared with the traditional flexed position for epidural placement, flexion with 10$^\circ$ dorsal table tilt and flexion with right rotation significantly increased the visualized length of the PLL as a measure of the acoustic target window.

The PLL as measured in our study and in previous studies is a composite echo of the anterior dura, PLL, and posterior vertebral body as it is not possible to delineate these structures as separate entities using currently available ultrasound technology.\textsuperscript{4, 7–8} Distinguishing between the PLL, anterior dura, and vertebral body is difficult and not relevant for the objective of our study. The rationale for using the PLL is based on the premise that an ‘open acoustic window’ is suggestive of an unobstructed path of the ultrasound energy to pass between the laminae through the dura, to the PLL. The PLL has previously been validated as a useful tool for assessment of the acoustic target window for neuraxial needle placement in the lumbar spine. In 60 adults undergoing lower extremity joint surgery under spinal anaesthesia, Weed and colleagues\textsuperscript{4} demonstrated that the positive predictive value of a low PLL score (0–8, indicative of poor visibility) was 82%, which was associated with a greater number of needle passes and increased technical difficulty with lumbar spinal anaesthesia. The positive likelihood ratio of a low PLL score was 12.8 and the negative likelihood ratio was 0.55, indicating that poor PLL visualization is associated with a high diagnostic yield for identification of technical problems with neuraxial access. The rationale for using the paramedian view is based on the study by Grau and colleagues\textsuperscript{16} who imaged the spine in 60 individuals and found that the paramedian approach provided superior images of the neuraxial structures and a larger paramedian target window compared with transverse and midline longitudinal approaches.

Visualization of the PLL and the clinical relevance of the observed changes in PLL length with position in our study also merit further discussion. Like Chin and colleagues,\textsuperscript{13–18} we found that the PLL was easily identifiable in all subjects in the thoracic region and was a reliable landmark for measurement. Interestingly, Jones and colleagues\textsuperscript{9} demonstrated an increase in the size of the acoustic target area by application of dorsal table tilt in the lumbar region but could not demonstrate any effect on interlaminar distances. However, we did not measure ligamentum flavum length as it is thin in the thoracic region and could not be reliably seen by ultrasound.\textsuperscript{13–15, 17}

In addition, the interlaminar distances were not measured because the corresponding measurement points on the laminae could not reliably be identified when subjects changed positions. The PLL, however, was the one structure that could be reliably visualized in the thoracic region in our
study and in part this could be due to the significantly larger acoustic window to shadow ratio in the paramedian view\textsuperscript{16} and the image quality of the PLL (Fig. 3) was good (Weed score \textsuperscript{4}).

Our principal finding was that dorsal table tilt and rotational movements of the spine increased the acoustic target area in the thoracic spine as indicated by the length of the PLL. Theoretically, a larger ‘target window’ should translate into a decreased incidence of bony contact and improve the success rate for correct placement of a needle for thoracic epidural anaesthesia. The magnitude of changes in the mean PLL length (from 9.9 to 13.8 mm) found in our study is comparable with changes in the mean ligamentum flavum length (from 10.7 to 11.2 mm) reported by Jones and colleagues.\textsuperscript{9} Since an epidural needle is \textasciitilde 1 mm in diameter, changes of such magnitude could theoretically make a difference in successful access to the epidural space and is therefore clinically relevant. Our findings could also provide a scientific basis to a management algorithm whereby difficult epidural access in the standard position could be followed by an attempt in one of the other positions presented in this study.

Explanation of our findings is based on the functional anatomy and biomechanics of the spine.\textsuperscript{19} In the lumbar spine, flexion is the principal mechanism for widening the interspinous and interlaminar spaces to facilitate neuraxial access. In the thoracic region, the thoracic vertebrae permit flexion and rotation of the spine to open the interlaminar space.\textsuperscript{19} Based on published literature on kinematics and biomechanics of the spine, flexion of the spine at each interspace increases moving caudally down the thoracic spine; with 3 – 5\textdegree of movement at T1–2 and increasing to 6 – 20\textdegree at T11–12.\textsuperscript{19}

Maximal flexion at the T9–10 interspace studied here has

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**Table 1** Lengths of the PLL (in mm) visualized by right-sided paramedian ultrasonography, at T9/10 intervertebral level, in five differing positions mean (SD), and summary of statistical differences between the neutral position (P1) and posterior–anterior flexion (P2) compared with each of the other study positions

<table>
<thead>
<tr>
<th>Volunteer position</th>
<th>P1 (Neutral)</th>
<th>P2 (PA flexion)</th>
<th>P3 (PA flexion and dorsal table tilt to 10\textdegree)</th>
<th>P4 (PA flexion and right (ipsilateral rotation))</th>
<th>P5 (PA flexion and left (contralateral rotation))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior longitudinal</td>
<td>9.9 (3.958)</td>
<td>11.79 (3.427)</td>
<td>12.9 (3.144)</td>
<td>13.83 (4.027)</td>
<td>11.14 (3.159)</td>
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<tr>
<td>ligament length</td>
<td></td>
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<td>P-value compared with</td>
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<td>position P1</td>
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<td>P-value compared with</td>
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<td>position P2</td>
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**Fig 3** Paramedian longitudinal ultrasound image showing the lamina, ligamentum flavum (LF)/posterior dura (PD), and the PLL/posterior vertebral body (PVB) between the lamina of T9 and T10.
been reported to be 8°. The application of dorsal table tilt most likely augments the degree of comfortable flexion achieved by a patient in the standard flexed position. Rotation of the spine in either direction at each interspace decreases moving causally down the spine; at T1–2, there is between 4° and 14° of movement, at T9–10, there is 3–5° and decreases to 2–3° at T11–12.19 20 With rotation, there is separation of the adjacent laminae and the spinous process sweeps away from the midline to open up the interlaminar space. This has not been previously studied as a potential manoeuvre to aid in epidural placement.

In this study, the ultrasound operator and the anaesthesiologist making the initial measurements could not be blinded to the patient position. To minimize reactive bias, the scanning anaesthesiologist was not allowed to see the PLL measurements and all PLL measurements were made by the second anaesthesiologist after all five scans had been saved in each patient. To further address observer and measurement bias, an independent consultant, blinded to the volunteer positions and previous PLL measurements, re-measured the PLL length on the archived images as suggested by Jones and colleagues.9 These data were utilized to obtain an intraclass correlation coefficient showing good agreement between the two measurements of PLL length. The order in which volunteers were positioned for scanning was not randomized because it was not practical or conducive to a systematic scanning technique. All our volunteers were young and healthy and had no difficulty assuming the required positions. Elderly, obese, and pregnant patients may not be able to tolerate these positions, so our study results may not be applicable to all populations. Two operators identified the start and endpoints of the visualized PLL to minimize structural identification error. The intrinsic software calculated the numerical value to minimize measurement inaccuracies. An important limitation of our study is that although the visualized portion of the PLL is increased in flexion-dorsal table tilt and flexion-right rotation, it can only be postulated that this increase in the ‘acoustic target window’ will translate into easier epidural insertion. Even though the study by Weed and colleagues4 is highly supportive of PLL as a predictor of difficult neuraxial insertion, the same cannot be said for our study until further validation in the form of clinical studies, which correlate PLL length in the thoracic region with the level of difficulty for epidural needle insertion.

We conclude that positioning the patient with either 10° of dorsal table tilt in flexion or right rotation in flexion increases interlaminar space as measured by an increased PLL length. Further clinical studies are required to determine if these positions improve the success rate of thoracic epidurals and allow for an easier and more efficient insertion.

Authors’ contributions
N.R.: design, conduct of study, data analysis, and manuscript preparation; J.W.: design, conduct of study, data analysis, and manuscript preparation; R.T.: study design, conduct of study, and manuscript preparation; H.V.: study design and manuscript preparation; A.S.: conduct of study and manuscript preparation.

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Declaration of interest
R.T. and A.S. both received equipment and travel support from Ultrasonix and acted as consultants for Ultrasonix in 2012.

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