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The anatomy of the thoracic spinal canal investigated with magnetic resonance imaging (MRI)

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Abstract : *Background and Objectives :* Anesthesiologists are reluctant to consider higher levels for spinal anesthesia, largely due to direct threats to the spinal cord. The goal of this study is to investigate, with magnetic resonance imaging (MRI), the distances between the relevant structures of the spinal canal (spinal cord, thecal tissue, etc.) to determine modal anatomical positions for neuraxial anesthesia.

Method : A group of 19 patients were imaged with an MRI scanner in supine position. Medial sagittal slices of the thoracic and lumbar spine were measured for the relative distances between anatomical structures, including epidural space, dura, and spinal cord.

Results : The posterior dura – spinal cord distance is significantly greater in the middle thoracic region than at upper and lower thoracic levels (e.g. T6 9.5 ± 1.8 mm, T12 3.7 ± 1.2 mm, $p < 0.001$, T1 4.7 ± 1.7 mm, $p < 0.001$). There is variation in modal distances between the structures important for neuraxial anesthesia, at different levels of the spinal canal.

Conclusions : The spinal cord tends to follow the straightest line through the imposed geometry of the spine. Considering the necessary angle of entry of the needle at mid-thoracic levels, there is relatively (more than at upper thoracic and lumbar levels) substantial separation of cord and surrounding thecal tissue. Anesthesiologists perform spinal blockades up to the L2-L3 interspace, but avoid higher levels for fear of neurological damage. The information that there is substantially more space in the dorsal subarachnoid space at thoracic level, might lead to potential applications in regional anesthesia. In contrast, the cauda equina sits more dorsally in the lumbar region.

Key words : Anatomy ; intrathecal ; MRI ; neuraxial ; spinal cord.

Introduction

In a recent article (1), we described a case in which a patient with significantly impaired lung function successfully underwent a cholecystectomy with segmental spinal anesthesia administered at the 10th thoracic interspace – much higher than the usual L2-L3, L3-L4 interspaces. Further, this technique has now been investigated in a feasibility study (2). The question remains, however, how risky such a spinal anesthetic approach may be in terms of direct trauma to the spinal cord from the needlepoint.

Interestingly, in the past, neurologists performed subarachnoid myelographic injections at thoracic and cervical levels (3). Even high spinal anesthesia has been employed for craniotomies (4). MRI and other imaging techniques have since rendered these myelographic procedures largely obsolete, although it is clearly possible to inject radiopaque or anesthetic agents into the subarachnoid space at the thoracic level. But what information does the anatomy provide as to the approximate margin of error allowed to the administering clinician ? To this end, we have revisited the anatomy of the spinal cord and surrounding tissues.

The same MRI techniques that replaced radiographic myelography have not previously been employed from an anesthesiology perspective to investigate the relative position of the pertinent

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structures (dura, cord, ligamentum flavum, etc.), for neuraxial anesthesia. This article seeks to define the relation of these structures, and identify possible implications for neuraxial anesthetic practice. The research presented here is restricted to imaging studies.

Methods

Nineteen patients (as described in Table 1) were imaged in an MRI scanner while recumbent in the supine position. All images were acquired on a 1.5 Tesla superconducting Philips MR scanner (Intera™ or NT release 9.0).

Each exam was made for clinical reasons (beyond this study, and unknown to the authors) using a standard hospital protocol. We acquired the images retrospectively from the hospital database, between 28th April and 28th June 2004, and 25th October and 25th December 2004. Exclusion criterion, as judged by a radiologist, was any pathology of the vertebral column and/or spinal cord. Sagittal slices were subsequently analyzed for this study.

Thoracic spine images were acquired using a synergy spine coil, for sagittal series with a F.O.V. (Field of View) ranging between 400 and 450 mm. (Matrix 512 × 512. T1 and T2 weighted, slice thickness 3mm. NSA (number of measurements) 3 for T1 and 4 for T2). Lumbar spine images were acquired with a synergy spine coil, for sagittal series with a F.O.V. of 350 mm (Matrix 512 × 512. T1 weighted : 4 mm slice thickness, NSA 2. T2 weighted : 4 mm slice thickness, NSA 3).

Subsequently, each patient's most medial slice, as assessed by the presence of the vertebrobasilar veins in image, was analyzed by a second independent physician, and the distance between relevant structures recorded on the image (Fig. 1). All measurements, including length of the spinal canal, were made using the built-in electronic calipers of the Philips Sectra PACS system. At each of the lumbar and thoracic interspaces, we measured (where applicable, i.e., no measurement of cord distances beyond cauda equina) skin to dura depth, posterior dura to cord distance, and epidural space depth on the line of the needle insertion ; and perpendicular to the cord, the posterior dura to cord distance, cord diameter, and anterior dura to cord distance.

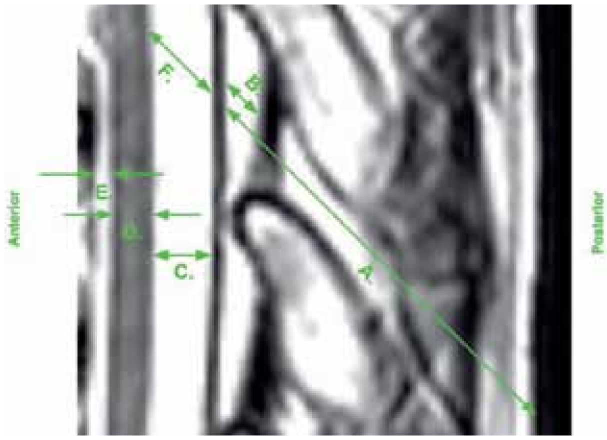

Fig. 1. — Magnified MR Image of thoracic spine, medial sagittal. This figure is an actual image from the data set. The arrows indicate the measured distances found in the study. A. Skin to dura ; B. Epidural space ; C. Posterior dura to cord ; D. Cord diameter ; E. Anterior dura to cord ; F. Posterior dura to cord in needle path.

All data analysis was done using MATLAB Version 7.1 (The MathWorks Inc., Natick, MA). We used the student t-test for comparison of two means, when illustrating the differences in geometry at certain interspaces of the spinal column. The data are presented in graphical format. Additionally, the data (each measured distance, every interspace) were tested for correlation with macro patient characteristics : height, sex, and weight. We did this using a linear Pearson's test for each of the measured parameters, at each respective interspace. $P < 0.05$ was considered statistically significant.

Table 1

Patient characteristics

	Male N = 6	Female N = 13
Age (years)	52 ± 19	45 ± 14
Weight (kg)	86 ± 9	70 ± 13
Height (cm)	181 ± 8	167 ± 5
Length of thoracic spinal canal (mm)	298 ± 15	281 ± 10

Results

The most important result of the study is the ventral position of the spinal cord in the thoracic curve ; in contrast to the more dorsal position of the spinal cord and cauda equina in the lumbar space (Fig. 2c and 3). Figure 2 presents measured distances between anatomical structures. The acquired images all showed common traits of lumbar lordosis and thoracic kyphosis of the spinal cord.

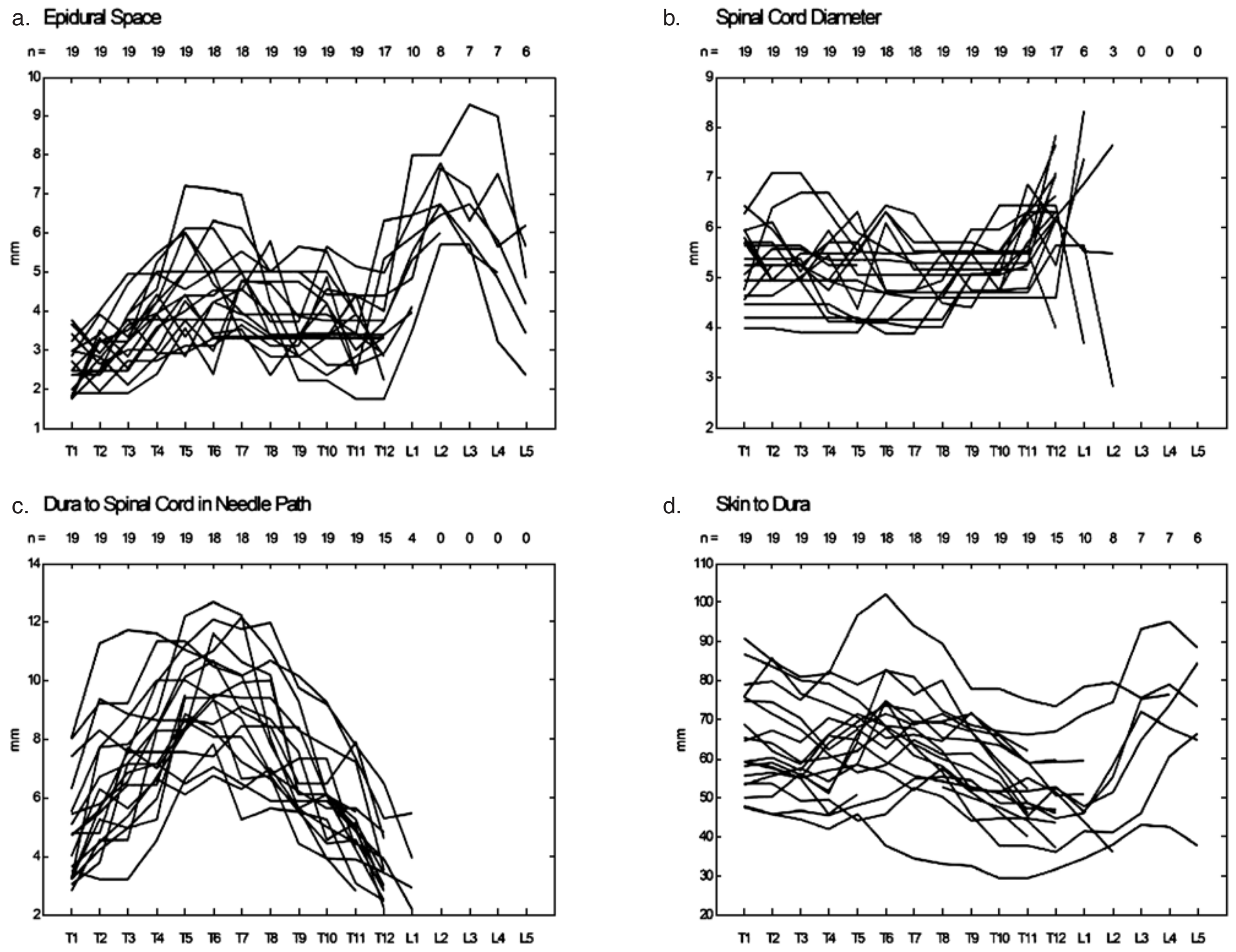

Fig. 2. — Line plots for respective patients of measured distances between various anatomical structures in the thoracic and lumbar spine. Distances in mm, and number of patients in group indicated above respective plots. Note the obvious increase in distance between cord and dura in the line of the needle insertion at middle thoracic levels in Figure 2c.

Anterior position of the spinal cord at thoracic level

Figure 3 indicates that the posterior subarachnoid space exceeds the anterior space in the thoracic region, and peaks in absolute dimensions at the mid-thoracic level. There are statistically significant differences between the posterior dura to cord distance on the needle path at middle thoracic level and at lower or upper thoracic level (e.g. T6 9.5 ± 1.8 mm, T12 3.7 ± 1.2 mm, $p < 0.001$) (T1 4.7 ± 1.7 mm, $p < 0.001$). Accordingly, the anterior dura to cord distance was the converse, with a small distance at the mid-thoracic level, and a greater distance more caudally or cephalad. At upper lumbar levels, the spinal cord termination in the cauda equina is dorsal within the spinal canal. The smallest distance that we measured between the dura and spinal cord at the T6 interspace was 3.2 mm perpendicular to the cord.

Additionally, the epidural depth (e.g. T6 4.5 ± 1.6 mm) is smaller ($p < 0.001$) than the posterior dura to spinal cord measurement (9.5 ± 1.8 mm) at the thoracic level, measured on the path of the needle. The anterior/posterior dimension of the epidural space is largest in the lumbar region (e.g. L1 5.4 ± 1.4 mm, T4 3.9 ± 0.9 mm, $p = 0.005$).

Correlation with macro patient characteristics

There was significant difference between women and men for the length of the thoracic spinal canal (men 298 ± 15 mm, women 281 ± 10 mm, $p = 0.008$). This corresponded to significant differences in height (men 181 ± 8 cm, women 167 ± 5 cm, $p < 0.001$). Otherwise, there were no other discernable differences between genders. The only exception was the correlation for weight with skin to dura distance. Heavier patients had a greater

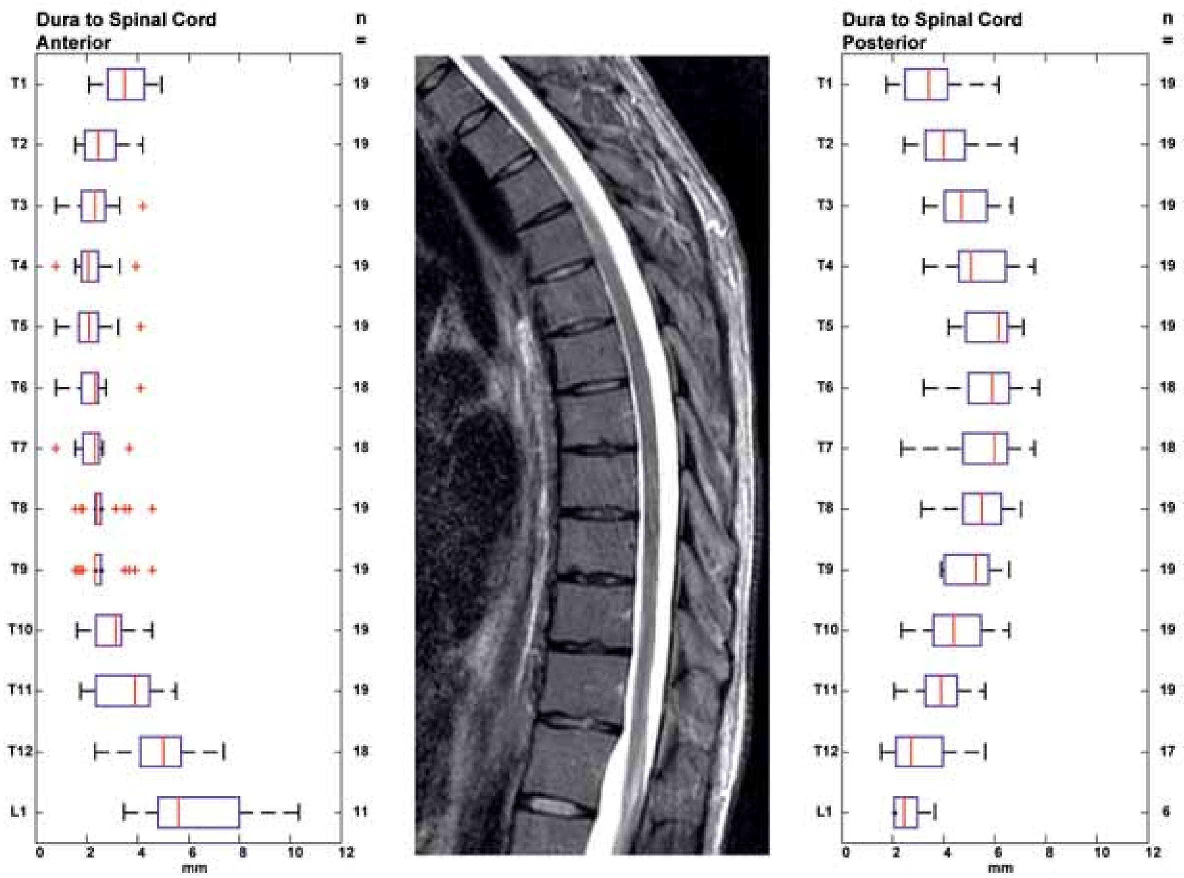

Fig. 3. — Box and Whisker plots of anterior and posterior dura to spinal cord distances. The spinal cord follows approximately the straightest line through the imposed geometry of the vertebrae. At thoracic levels the cord lies ventral in the apex of the thoracic curve, whilst the cauda equina terminates dorsally at lumbar levels. The left hand figure indicates the anterior dura to cord distance, and the right-hand figure the posterior dura to cord distance. Both distances are measured perpendicular to the cord.

distance between skin and dura (correlation of patient weight vs. skin to dura depth for respective interspaces 0.57-0.95, $p < 0.05$ for all interspaces).

Discussion

The most important result of the study is the ventral position of the spinal cord itself within the dural sheath while supine at thoracic levels, in contrast to the dorsal position of the spinal cord and cauda equina in the lumbar region. Figure 2c, and Figure 3 both indicate the clear trend for the cord to lie, at thoracic levels, towards the anterior border of the dura.

The incidence of serious neurological complications in epidural procedures is far lower than that of the incidence of inadvertent dural tap (5). It is evident from the case study and feasibility study from van Zundert *et al.* (1, 2), that there may be benefits to the practice of spinal blockades at higher levels. A pertinent question arising from this technique of van Zundert *et al.* (1), mentioned in the introduction, is that of the safety of performing thoracic spinal blockade.

Our result of the anterior position of the cord at thoracic levels indicates that intrathecal injections at these high levels may have a greater absolute margin of error before needle contact with neural tissue. It is well known that the geometry of the processes dictates the angle of entry of the needle for mid-line neuraxial blockade, and this contributes to extra space between dura and spinal cord posterior at thoracic levels. The lower thoracic and lumbar levels, as well as high thoracic levels, lack this safety feature. Especially, if a combined spinal – epidural (CSE) technique is employed to first identify the epidural space correctly, there may be better perception of the dural penetration with spinal needle than in a straight spinal injection. We hope our observations in this study may provide impetus for more investigation.

We confirm that the anterior-posterior dimension of the epidural space is widest in the lumbar region (6). Also, in concurrence with previous cadaver studies of the spinal cord and subarachnoid space, we found little consistent correlation between the respective measurements and any of sex, weight, or height (7).

The present study investigates tissue dimensions in the supine position. Most neuraxial blockades are performed with the patient in a sitting position, or lateral decubitus. It is unlikely that there is great displacement of the tissues relative to each other in various postures. Although the dura may slide longitudinally in the spinal canal (8, 9), only minor movement of fat and accumulation of epidural venous blood may hinder change of dural dimensions (10). Additionally, the cord is securely tethered in the anterior/posterior dimension by the dentate ligaments. It is noticeable that the spinal cord lies approximately most anterior at the apex of the thoracic curve (conversely, most posterior at the lumbar and cervical curves). Considering the geometry, it is expected, with the patient in a sitting or recumbent position with exaggerated curvature of the back (to facilitate greater room between the processes of the spine) the cord would tend to lie even further anteriorly.

A problem to consider in imaging studies is the scanner resolution, which in the present study is in the order of 0.6 mm pixel size, in plane. This implies an error margin in the measurements of the same order of magnitude. For the assumption of images which are medial, we can consider the slice size. The maximum slice size is 4 mm. For the smallest cord diameter measured this would imply an error in the range of ± 0.5 mm. Other contributions to error include patient alignment, image segmentation, and discretization of the measurement tool. We estimate total error for any single measurement in the order of ± 2 mm, very conservatively.

Conclusion

This study considers the geometry of the problem for viable insertion of the administering needle in spinal-epidural anesthesia. There are clear differences in the relative distances between structures around the spinal cord at various levels of the spinal column. Specifically, there is a greater depth of the posterior subarachnoid space at mid-thoracic levels than at lumbar and upper thoracic levels. This indicates that potentially there is more space available for intrathecal delivery of anesthetic drugs while avoiding spinal cord contact in the thoracic region.

Future study will investigate more clinically relevant patient postures, and possibly imaging during actual punctures.

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References

1. van Zundert A. A., Stultiens G., Jakimowicz J. J., van den Borne B. E., van der Ham W. G., Wildsmith J. A., *Segmental spinal anaesthesia for cholecystectomy in a patient with severe lung disease*, Br. J. Anaesth., **96**, 464-466, 2006.
2. van Zundert A. A., Stultiens G., Jakimowicz J. J., Peek D., van der Ham W. G., Korsten H. H., Wildsmith J. A., *Laparoscopic cholecystectomy under segmental thoracic spinal anaesthesia : a feasibility study*, Br. J. Anaesth., **98**, 682-686, 2007.
3. Robertson H. J., Smith R. D., *Cervical myelography : survey of modes of practice and major complications*, Radiology, **174**, 79-83, 1990.
4. Jonnesco T., *Remarks on general spinal anesthesia*, Br. Med. J., **2**, 1935-40, 1909.
5. Horlocker T. T., Wedel D. J., *Neurologic complications of spinal and epidural anesthesia*, Reg. Anesth. Pain Med., **25**, 83-98, 2000.
6. Bromage P. R., Epidural Analgesia, Saunders, 197, 1978.
7. Nordqvist L., *The Sagittal Diameter of the Spinal Cord and Subarachnoid Space in Different Age Groups. A Roentgenographic Post-Mortem Study*, Acta Radiol. Diagn. (Stockh.), **61**, Suppl. 227, 221-296, 1964.
8. Takiguchi T., Yamaguchi S., Hashizume Y., Kitajima T., *Movement of the Cauda Equina during the lateral decubitus position with fully flexed leg*, Anesthesiology, **101**, 1250, 2004.
9. Takiguchi T., Yamaguchi S., Okuda Y., Kitajima T., *Deviation of the cauda equina by changing position*, Anesthesiology, **100**, 754-755, 2004.
10. Hogan Q., *Size of human lower thoracic and lumbosacral nerve roots*, Anesthesiology, **85**, 37-42, 1996.