The Anatomy of the Thoracic Spinal Canal in Different Postures

A Magnetic Resonance Imaging Investigation

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Background and Objectives: The goal of this study was to investigate, with magnetic resonance imaging, the human anatomic positions of the spinal canal (eg, spinal cord, thecal tissue) in various postures and identify possible implications from different patient positioning for neuraxial anesthetic practice.

Method: Nine volunteers underwent magnetic resonance imaging in supine, laterally recumbent, and sitting (head-down) positions. Axial and sagittal slices of the thoracic and lumbar spine were measured for the relative distances between anatomic structures, including dura mater and spinal cord.

Results: The posterior dura–spinal cord (midline) distance is on average greater than the anterior dura–spinal cord (midline) distance along the thoracic spinal column, irrespective of volunteer postures ($P < 0.05$). The separation of the dura mater and spinal cord is greatest posterior in the middle thoracic region compared with upper and lower thoracic levels for all postures of the volunteers ($P < 0.05$). By placing the patient in a head-down sitting posture (as commonly done in epidural and spinal anesthesia), the posterior separation of the dura mater and spinal cord is increased.

Conclusions: The spinal cord follows the straightest line through the imposed geometry of the spinal canal. Accordingly, there is relatively more posterior separation of the cord and surrounding thecal tissue at midthoracic levels in the apex of the thoracic kyphosis. Placing a patient in a position that accentuates the thoracic curvature of the spine (ie, sitting head-down) increases the posterior separation of the spinal cord and dural sheath at thoracic levels.

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In the past, high spinal anesthesia has been used for craniotomies,[1] and before the introduction of magnetic resonance imaging (MRI), neurologists and radiologists performed subarachnoid myelographic injections at mainly cervical (and occasionally thoracic) levels.[2] Subarachnoid punctures are still used for cancer pain relief at thoracic (subarachnoid catheter)[3] and cervical (cordotomy)[4,5] levels.

The same MRI techniques that replaced radiographic myelography have been used recently for the investigation of the position of the spinal cord and surrounding structures (ie, dura mater, spinal processes) in a group of patients in the supine position.[6] The restriction of this previous study to supine positions limits its applicability for the clinical practice where neuraxial anesthesia is almost always performed in a sitting or laterally recumbent posture. This article seeks to define the relationship of the spinal cord and surrounding structures to each other along the thoracic spinal column. The research presented here is restricted to MRI imaging studies.

METHODS

Nine volunteers underwent MRI in 3 postures: recumbent in the supine position, laterally recumbent, and sitting (head-down). Exclusion criteria were deformity or pathology of the vertebral column and/or spinal cord, any history of back complications, body mass index greater than 30 kg/m^2, and volunteers younger than 18 years. Each volunteer received a description of the research and gave written informed consent to participate before the study. The study received consent of the ethical committee of the participating authors' hospital (Catharina Hospital, Eindhoven, the Netherlands) and was registered with the national auditing commission for human trials in the Netherlands. All examinations were acquired on a 0.6-T FONAR Upright Multi-Position MRI scanner (Fonar Corporation, Melville, NY) (Fig. 1). Axial/horizontal slices were subsequently analyzed for this study.

Thoracic spine images were acquired using a FONAR Signal Plus Wide Belt thoracic-lumbar spine 45″ (surface) coil for fast spin echo. T2 sagittal series (repetition time, 1645 milliseconds; time to echo, 160 milliseconds) had a field of view of 360 mm (matrix, 256 × 256; slice thickness, 4.5 mm; 3 measurements; and flip angle, 90 degrees). T2 axial slices (repetition time, 1494 milliseconds; time to echo, 120 milliseconds) had a field of view of 250 mm (matrix, 256 × 256; slice thickness, 4.5 mm; 2 measurements; and flip angle, 90 degrees).

Axial images through the middle of the spinal bodies T1, T3, T6, T9, and T12 were segmented and measured by an independent radiologist with the help of custom-built modules within the DeVIDE image processing and visualization environment (Data Visualization Group, Delft University of Technology, Delft, the Netherlands).[7] The dural sac and spinal cord were approximated with ellipse fitting, whereby the radiologist

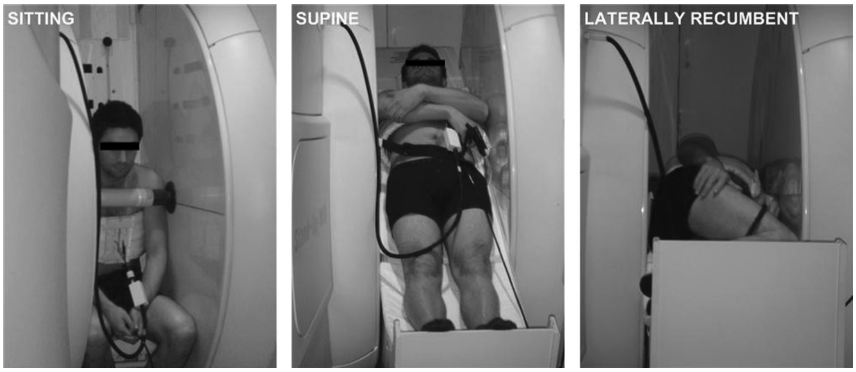

FIGURE 1. Volunteer positioned (left-to-right, sitting, supine, and laterally recumbent) in the FONAR Upright Multi-Position MR scanner (Fonar Corporation) with antenna attached around thorax. The volunteers were not limited in the curvature of their backs in the sitting position, and the volunteers had more curved backs and head-down positions during the measurements—contrary to the straight-backed position illustrated in this figure. (Permissions were obtained for publication of these images).

was required to interactively manipulate ellipses overlaid on axial images to best fit the anatomic structures. The skin segmentation was achieved with automatic 2-dimensional region growing techniques. The distances between the skin and dura, posterior dura-cord distance, cord "diameter" in the needle "direction," and anterior cord-dura distance were all automatically measured, both for midline and paramedian (taken to be 20 degrees to median) (Fig. 2). Ambiguous images (ie, movement artifacts) as determined by the radiologist, such that the segmentation was difficult, were excluded.

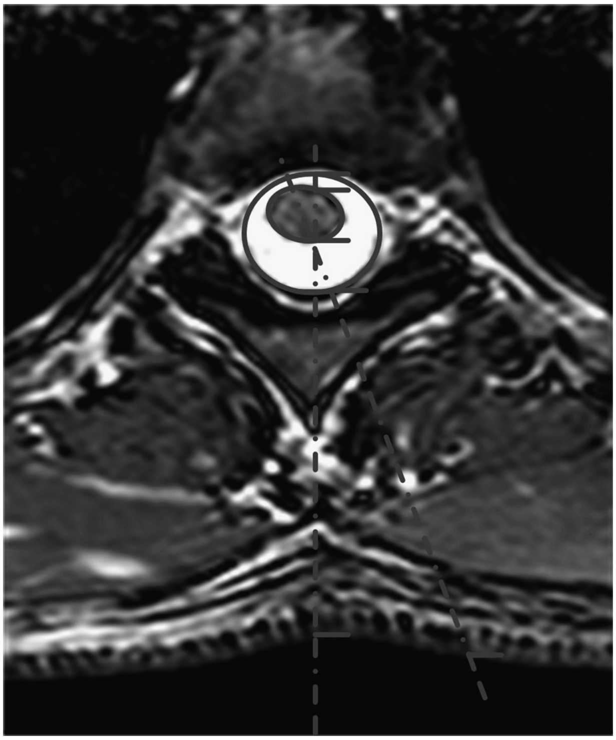

FIGURE 2. Segmentation of the axial MRI images. The MRI image is from the actual data set and shows the spinal cord and dural sac modeled using an ellipsoid approximation, while the measurements are automatically taken.

The data presented in the figures were prepared using MATLAB version 7.1 (The MathWorks Inc, Natick, Mass). First, the data were tested for linear correlation with macro volunteer characteristics of weight, height, and age using Pearson product moment correlation. This correlation test was performed on midline measurements from the axial images, with Bonferroni correction for the multiple hypothesis testing. Imbalance was introduced into the study design through the images deemed too ambiguous for the segmentation. Imbalances due to these dropouts were considered "missing completely at random" from Little test (χ^2 = 64, P = 1.00) and no conceivable dependability of the missing values on other dropouts or the fundamental study design.[8,9] Expectation maximization methods failed to converge, so we conservatively assumed mean values for the missing values of the respective patients (ie, the null hypothesis that there was no effect of either volunteer posture or height of the measurement). The differences in relative positions of the anatomic structures were investigated using repeated-measures multivariate analysis, with Hotelling trace as the test statistic. The height of the thoracic spinal canal and the volunteer postures were considered as within-subject treatments.[10] This analysis was performed using SPSS version 14.0 (SPSS Inc, Chicago, Ill). The tests were carried out for all of the axial-median, and axial-paramedian measurements. $P < 0.05$ was considered statistically significant.

RESULTS

Our 9 volunteers consisted of 3 women (age, 29 ± 6 years; weight, 55 ± 3 kg; height, 164 ± 5 cm) and 6 men (age, 40 ± 17 years; weight, 84 ± 9 kg; height, 182 ± 5 cm). The posterior separation of the spinal cord and surrounding thecal tissue was greatest in the apex of the thoracic curve at midthoracic levels in contrast to the more dorsal location of the spinal cord at high thoracic and low thoracic levels for every posture. The full measurements are available as Table, Supplemental Digital Content 1, http://links.lww.com/AAP/A21. Figure 3 presents box plots of the posterior separations between spinal cord and dura for each of the patient postures. A sitting posture (head down) increased the midline posterior separation of the spinal cord and thecal tissue compared with supine or laterally recumbent postures in the middle of the thoracic curve. All the

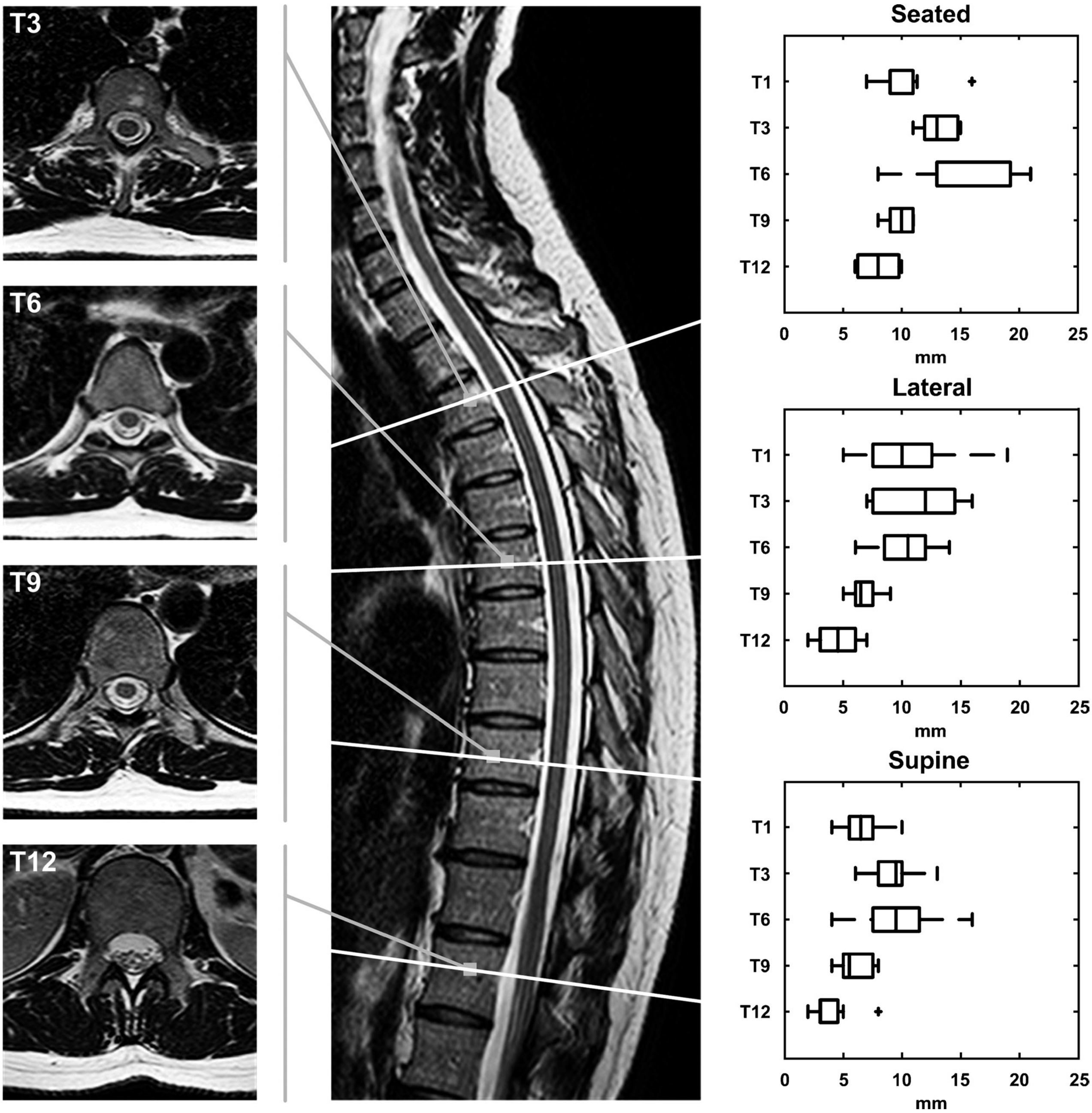

FIGURE 3. Box plots (median, lower and upper quartiles, range of the data, and eventual outliers indicated) of midline measurements from the axial data set showing the measured distance between dura and spinal cord posteriorly. This figure shows (1) significant variation in the volunteer population; (2) a clear parabolic trend for greater separation of dura and spinal cord at midthoracic levels (cord somewhat anterior at T3, almost completely anterior at T6 and T9, and posterior at T12 at the medullary cone and the beginning of the cauda equina); and (3) a trend for greater separation between the posterior dura and cord when the posture of the volunteer accentuates the curvature of the thoracic column (ie, sitting and laterally recumbent compared with supine). To the left are MRI images showing the positioning of the spinal cord at various interspaces, from a volunteer in supine position (T1 image excluded).

acquired images showed common traits of lumbar lordosis and thoracic kyphosis of the spinal column.

There was no significant difference between the results for male or female subjects. There was no correlation between the patient characteristics and the relative distances measured between the structures of the spinal column. The only exception was a correlation between the height and weight of the subject to the skin-to-dura distance. Heavier subjects had a greater distance between skin and dura ($r = 0.95$, $P < 0.01$). Taller subjects similarly had greater distances between skin and dura ($r = 0.85$, $P < 0.01$).

Considering first midline measurements, there was an overall greater separation of the dura from the spinal cord posteriorly in sitting postures with regard to both laterally recumbent and supine posture ($F = 10.59$, $P < 0.01$). The effect size was small

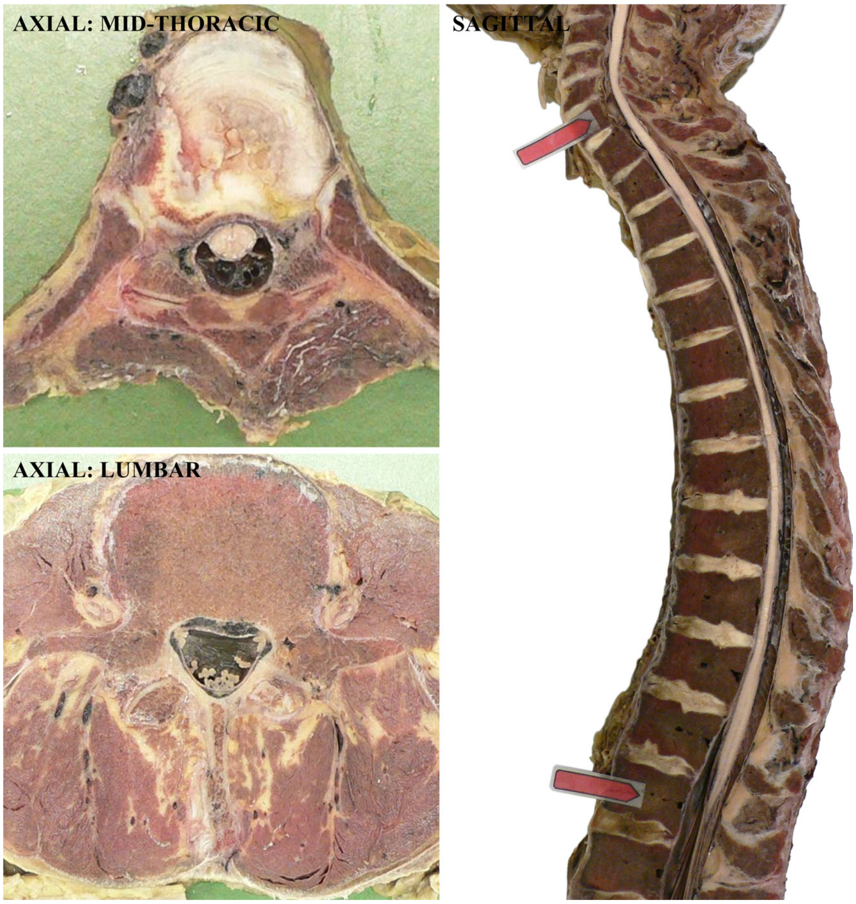

FIGURE 4. Anatomic sagittal section of the spinal cord in a human cadaver (arrows indicate C7 and L1, respectively). The image also indicates the relatively anterior position of the cord through the thoracic curve of the spinal column, leaving a large distance between the thoracic spinal cord and the dura mater posteriorly. At the lumbar level, the spinal cord and especially the cauda equina take the posterior position.

between sitting and laterally recumbent postures; the estimated marginal mean was approximately 0.3 mm. Between sitting and supine, the estimated marginal mean was approximately 1 mm. There was similarly greater separation of the dura mater from the spinal cord posteriorly at midthoracic levels compared with both high and low thoracic ($F = 6.37$, $P = 0.049$) interspaces. In all postures, there was maximum separation of the spinal cord from its dural sheath posterior at the measured T6 or T9 interspace. At T1 and T12, this separation was the least.

The inverse of these findings was true for the anterior separation of the cord from the dura being greatest in supine posture ($F = 5.437$, $P = 0.037$). No significant influence was found from the level of the measurement on the anterior separation ($F = 4.374$, $P = 0.089$). There were differences between the distances from the skin to the dura for the different patient postures. Placing a patient in a sitting posture (pooled mean, 37 mm) evidently decreases the distance between the skin and dura mater, compared with laterally recumbent (pooled mean, 40 mm) patients ($F = 15.83$, $P < 0.01$). There was no significant dependency of the cross-sectional area of the spinal cord or the area enclosed by the dural sac with either the height of the spinal column or posture of the patient.

The paramedian measurements (taken at 20 degrees to the median images) showed similar results. There was greater separation between the dura mater and spinal cord posterior in sitting and laterally recumbent postures relative to supine ($F = 18.001$, $P < 0.01$). The pooled effect size was an estimated marginal mean of 0.6 mm. However, there was no significant effect of the height of the spinal column on the posterior dura-to-cord measurement ($P = 0.08$).

DISCUSSION

This MRI study in human volunteers demonstrates that the spinal cord lies ventrally within the dural sheath at midthoracic levels, essentially following the imposed geometry of the spinal column. In contrast, at upper and lower thoracic levels, the spinal cord is positioned more dorsally[6] (and presumably, also the cauda equine at lumbar levels).[11]

In concurrence with previous cadaver studies of the spinal cord and subarachnoid space, we found little consistent correlation between the respective measurements and either weight or height.[12] Furthermore, we found that it was appropriate to pool the data from the female and male volunteers, because there were no measureable differences in our study. This is in concurrence with other studies that showed that there was no difference between the sexes.[6,12,13] The present study investigates the relative spacing between anatomic structures in sitting, laterally recumbent, and, of less clinical relevance, supine position. Most neuraxial blockades are performed with the patient in a sitting or laterally recumbent position. Other authors have previously noted that displacement of the spinal tissues relative to each other is unlikely[14] and that the posture of the patient has plausibly little effect on the anatomic positions. Although the dura mater is shown to slide longitudinally in the spinal canal,[15,16] only minor movement of fat and accumulation of epidural venous blood may hinder change of dural dimensions.[17] The denticulate ligament, tethering the spinal cord, allows for some movement of the cord in the anterior/posterior dimension, as our result demonstrates. From this study, it is noticeable that the spinal cord approximately lies most anterior at the apex of the thoracic curve (Fig. 4). Considering the spinal canal geometry and that the cord can translocate, the result that the cord sits even further anterior in the thoracic curve with the patient in a sitting or recumbent position with exaggerated curvature of the spine is logical. Greater accentuation of this curvature (ie, achieved by placing a patient in a sitting, head-down posture) will increase the posterior separation of the dura and spinal cord in the apex of the thoracic curve. The converse has been noticed in clinical practice, with spinal punctures at lumbar levels often incurring almost immediate contact with neural tissue once the dura is punctured (Fig. 4, Axial: Lumbar). Indeed, paresthesia during the insertion of a spinal needle at the lumbar level is not uncommon, with incidences up to 14%.[18]

Our study has several limitations, including the following. (1) Volunteers were imaged in clinically relevant postures, although it was impossible to place the volunteers in a complete legs-up position, as the "tunnel" of the MRI scanner was too narrow. Raising the legs may increase the kyphosis of the thoracic spine, thereby increasing the posterior separation between the spinal cord and dura mater. Clearly, this study infers that patients who can poorly curve their back (eg, the elderly) or patients incapable of bending (eg, trauma, etc) will have less distance between the dura mater and spinal cord at thoracic levels. In such instances, even greater care should be taken with epidurals. (2) The MRI study did not include the volunteers in the sitting position without head-down, and therefore, we cannot compare the influence of the cervical flexion on the position of the spinal cord within the spinal canal. (3) We included volunteers with a normally flexible back. Hence, we cannot extrapolate our findings to patients with inflexible backs (eg, the elderly). (4) 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. There should not be a directional bias for this error that could affect the conclusions drawn from this study. Other contributions to error include patient alignment, image segmentation, and discretization of the measurement tool. (5) Our study is a study of MRI-obtained measurements that have no clinical component. We only can speculate on its implications for clinical practice. However, we know that epidural attempts can result in unintentional puncture of the dura mater, both at the thoracic[19] and lumbar[20] spaces, potentially resulting in unintentional damage to the spinal cord. The relatively wide posterior subdural space at the thoracic level potentially allows the Tuohy needle to be halted before it contacts the pia mater or penetrates into the spinal tissue. The incidence of serious neurologic complications in thoracic epidural procedures is far lower than that of the incidence of unintentional dural tap,[19] and there may be benefits to the practice of spinal blockades at higher levels,[21,22] although this awaits more clinical investigation and documentation. Because of considerable anatomic variation among patients, and no clear correlations as yet between patient characteristics and the distances of pertinent structures of the spinal canal, these findings should be interpreted cautiously.

CONCLUSIONS

This study investigated the orientation of the spinal cord along the spinal canal at different thoracic levels and in different volunteer positions (ie, supine, sitting [head-down], and laterally recumbent). We noted that the distances between the posterior dura mater and the spinal cord was widest at the midthoracic region and with the volunteer in the sitting position (head-down). Essentially, the cord follows the imposed geometry of the spine, which in turn means that placing a patient in a posture with exaggerated curvature of the thoracic column (sitting, head-down) will accentuate this anterior position in the thoracic curve.

REFERENCES

1. Jonnescu T. Remarks on general spinal anesthesia. *Br Med J.* 1909;2:1935.
2. Robertson HJ, Smith RD. Cervical myelography: survey of modes of practice and major complications. *Radiology.* 1990;174: 79–83.
3. El-Sayed GG. A new catheter technique for thoracic subarachnoid neurolysis in advanced lung cancer patients. *Pain Pract*. 2007;7:27–30.
4. Zuurmond WW, Perez RS, Loer SA. Role of cervical cordotomy and other neurolytic procedures in thoracic cancer pain [published online ahead of print]. *Curr Opin Support Palliat Care*. 2010;4:6–10.
5. McGirt MJ, Villavicencio AT, Bulsara KR, Gorecki J. MRI-guided frameless stereotactic percutaneous cordotomy. *Stereotact Funct Neurosurg*. 2002;78:53–63.
6. Lee RA, van Zundert AA, Breedveld P, Wondergem JH, Peek D, Wieringa PA. The anatomy of the thoracic spinal canal investigated with magnetic resonance imaging (MRI). *Acta Anaesth Belg*. 2007;58:163–167.
7. Botha CP, Post FH. *Hybrid Scheduling in the DeVIDE Dataflow Visualisation Environment Simulation and Visualization*. Hauser H, Strassburger S, Theisel H, eds. Erlangen, Germany: SCS Publishing House; 2008:309–322.
8. Schafer JL. Analysis of incomplete multivariate data. London, UK: Chapman and Hall; 1997.
9. Little RJA, Rubin DB. *Statistical Analysis With Missing Data*. New York: John Wiley and Sons; 1987.
10. Keppel G, Wickens TD. *Design and Analysis: A Researcher's Handbook*. 4th ed. Englewood Cliffs, NJ: Prentice Hall; 2004.
11. Tagiguchi T, Yamaguchi S, Tezuka M, Kitajima T. Measurement of shift of the cauda equina in the subarachnoid space by changing position. *Reg Anesth Pain Med*. 2009;34:326–329.
12. 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)*. 1964;61: (suppl 227):1–96.
13. Hogan QH. Epidural anatomy examined by cryomicrotome section. Influence of age, vertebral level, and disease. *Reg Anesth*. 1996;21:395–406.
14. Hogan Q, Toth J. Anatomy of soft tissues of the spinal canal. *Reg Anesth Pain Med*. 1999;24:303–310.
15. Takiguchi T, Yamaguchi S, Hashizume Y, Kitajima T. Movement of the cauda equina during the lateral decubitus position with fully flexed leg. *Anesthesiology.* 2004;101:1250.

16. Takiguchi T, Yamaguchi S, Okuda Y, Kitajima T. Deviation of the cauda equina by changing position. *Anesthesiology.* 2004;100:754–755.
17. Hogan Q. Size of human lower thoracic and lumbosacral nerve roots. *Anesthesiology.* 1996;85:37–42.
18. Pong RP, Gmelch BS, Bernards CM. Does a paresthesia during spinal needle insertion indicate intrathecal needle placement? *Reg Anesth Pain Med*. 2009;34:29–32.
19. Giebler RM, Scherer RU, Peters J. Incidence of neurological complications related to thoracic epidural catheterization. *Anesthesiology.* 1997;86:55–63.
20. Horlocker TT, Wedel DJ. Neurologic complications of spinal and epidural anesthesia. *Reg Anesth Pain Med*. 2000;25: 83–98.
21. van Zundert AA, Stultiens G, Jakimowicz JJ, van den Borne BE, van der Ham WG, Wildsmith JA. Segmental spinal anaesthesia for cholecystectomy in a patient with severe lung disease. *Br J Anaesth*. 2006;96:464–466.
22. van Zundert AA, Stultiens G, Jakimowicz JJ, et al. Laparoscopic cholecystectomy under segmental thoracic spinal anaesthesia: a feasibility study. *Br J Anaesth*. 2007;98:682–686.