Changing body position alters the location of the spinal cord within the vertebral canal: a magnetic resonance imaging study

M. R. B. Ranger1,3*, G. J. Irwin2, K. M. Bunbury1,4 and J. M. Peutrell1

1Department of Anaesthesia and 2Department of Radiology, The Royal Hospital for Sick Children, Yorkhill, Glasgow G3 8SJ, UK
3Present address: Department of Anaesthetics, Mater Children’s Hospital, Raymond Terrace, South Brisbane, QLD 4101, Australia
4Present address: Department of Anaesthesia and Perioperative Medicine, The Alfred Hospital, Commercial Road, Prahran, VIC 3181, Australia
*Corresponding author: Department of Anaesthetics, Mater Children’s Hospital, Raymond Terrace, South Brisbane, QLD 4101, Australia. E-mail: bygeorge@doctors.org.uk

Background. The influence of changes in body position relevant to neuraxial blockade on the location of the spinal cord and related neural structures has not been fully quantified. Our aim was to determine the changes, if any, that occur in the location of the spinal cord tip [equivalent to the tip of the conus medullaris (CM)] and nerve roots when an individual moves from the supine to the lateral position with knees and hips flexed.

Methods. We used magnetic resonance imaging to determine movement of the spinal cord tip and associated structures in 30 adult volunteers.

Results. The tip shifted both anteriorly [average 6.3 mm, standard deviation (SD) 2.15 mm; P < 0.001] and laterally towards the dependent side (average 1.63 mm, SD 1.19 mm; P < 0.001). Although we observed anterior shift in all 30 volunteers, lateral movement did not occur in seven. Movement along the cranio-caudal axis was not statistically significant.

Conclusions. Both the CM and associated nerve roots shift consistently and significantly anteriorly when moving from the supine to the lateral position with knees and hips flexed, which may provide a greater margin of safety during neuraxial blockade than might be predicted. However, the absence of significant cranial movement of the CM along the cranio-caudal axis still makes the spinal cord vulnerable to injury during lumbar neuraxial blockade.

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The anatomy of the spinal cord and associated structures has been well defined,1,2 largely based on post-mortem or imaging studies in the supine or prone positions. This includes structures relevant to neuraxial anaesthesia, such as the termination of the spinal cord and dural sac,3 the vertebral level and shape of the conus medullaris (CM),4 the shape of the epidural space,5–7 and distances from the skin to the epidural or subarachnoid spaces.8–11 However, the effects of body position (particularly positions relevant to neuraxial blockade) on the location of the spinal cord and other neural structures have not been well studied.12–16

Our objective was to quantify the change that occurs, if any, in the location of the spinal cord tip (equivalent to the tip of the CM) and nerve roots when an individual moves from the supine to the left lateral position with knees and hips flexed.

Methods

After obtaining approval from the local research ethics committee and written informed consent, we recruited 34 healthy adult volunteers with no contraindications to magnetic resonance imaging (MRI). Further exclusions...
included previous back surgery, current back problems, pregnancy, and a body shape or size that would not allow volunteers to lie laterally in the scanner in comfort.

Before scanning, we measured and recorded each volunteer’s weight and height and calculated their BMI \[\text{BMI} = \frac{\text{weight (kg)}}{\text{height (m}^2\text{)}}\]. Volunteers then sat on a trolley with their neck and back fully flexed, adopting the standard position described for neuraxial blockade.\(^\text{17}\) One of the two authors then identified the T\(_{12}/L\_1\) intervertebral space by palpating the intercristal line (which intersects the midline at either the L\(_4\) spinous process or the L\(_4/L_5\) interspace)\(^\text{8 18}\) and counting upwards. A cod-liver oil capsule (skin marker) was firmly secured with tape over the T\(_{12}/L_1\) interspace to provide a distal reference point for the vertebral level on the MRI scans.

The dedicated R1 surface coil was then strapped to the volunteer’s back along the line of the thoraco-lumbar spine. Using a Philips Intera 1.5 Tesla scanner and predetermined protocol, we then performed a total of five scan sequences in two body positions.

The volunteer first lay in a neutral supine position with the head on a pillow. We then scanned the spine from the cranio-cervical junction down to the skin marker using the integral Q Body coil and a sagittal T2 DRIVE sequence (first or reference scan) and precisely identified the vertebral level of the skin marker by counting from C\(_1\). The high-resolution surface coil was used for subsequent scans, focusing only on the lower thoracic and lumbar regions with the skin marker providing a reference from which to identify each vertebra. We then obtained images of the thoraco-lumbar region (including the CM and skin marker) using a sagittal T2 DRIVE sequence (second scan) and the CM using an axial balanced turbo field echo (BTFE) scan (third scan). The imaging software allowed correlation of the vertebral level between these two scans.

Each volunteer then lay in the left lateral position, with the vertebral column, hips, and knees flexed to mimic the posture adopted during neuraxial blockade and head resting on a pillow. Both the sagittal T2 DRIVE and axial BTFE scans (scans 4 and 5) were then repeated.

From the high-resolution images in both positions, we were able to clearly identify each vertebral level. Using a high-resolution Merge eFilm Workstation 1.9.1, a consultant radiologist made direct measurements from the digital images. The junction of the CM with the filum terminale was used as the most identifiable and easily reproducible indicator of the tip of the spinal cord. This was determined for each body position as:

(i) the distance (D\(_1\)) from the middle of the posterior wall of the dural sac to the spinal cord tip (Fig. 1). This was not always in the sagittal plane, but the mid-point of the posterior dura provided the most recognizable feature from which to make reproducible measurements.

(ii) the distance (D\(_2\)) of the spinal cord tip from the mid-sagittal plane (lateral displacement) (Fig. 1);

(iii) the vertebral level of the spinal cord tip defined\(^\text{18}\) by dividing the vertebral body and intervertebral space into four segments: upper, middle and lower thirds, and the intervertebral space (Fig. 2).

From these measurements, we determined any shift of the spinal cord tip anterior-laterally and along the cranio-caudal axis and made qualitative observations on the appearance of the cauda equina.

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**Fig 1** Schematic representation of a transverse section through a lumbar vertebra at the level of the CM. The nerve roots are marked as small open circles; the tip of the spinal cord is indicated by the larger, single closed circle.
Changes in cord positions were analysed using Wilcoxon tests. The effects of age, gender, and BMI were tested using a general linear model, allowing for linear transformations or linear combinations of multiple dependent variables. All analyses were made using Minitab 14 (Minitab Ltd, Coventry, UK) with a significance of 5% (P, 0.05).

Results

We reviewed images from 30 of the 34 volunteers (Table 1). Two did not complete scanning because of claustrophobia. The images of two others could not be analysed because of movement artifact or anatomical abnormality.

Gender, age, and BMI had no significant effect on CM movement.

On average, D1 increased by 6.3 mm [standard deviation (SD) 2.15 mm] and D2 increased by 1.63 mm laterally towards the dependent side (SD 1.19 mm) when moving from the supine to the left lateral position with knees and hips flexed (Fig. 3). The shift was significant in both directions (Wilcoxon P<0.001) compared with a null hypothesis of zero shift (95% confidence intervals 5.5, 7.0 mm D1 movement; 1.0, 2.0 mm D2). However, although we observed that D1 increased in all volunteers, lateral movement did not occur in seven.

In both supine and lateral positions, the spinal cord tip lay between the lower third of T12 and the lower third of the vertebral body, including the intervertebral space into four segments: upper, middle and lower thirds, and the intervertebral space.18

Fig 2 The level of the tip of the CM is defined by dividing the vertebral body, including the intervertebral space into four segments: upper, middle and lower thirds, and the intervertebral space.18

Table 1 Characteristics of the volunteers by gender (13 males, 17 females). SD, standard deviation; BMI, body mass index

<table>
<thead>
<tr>
<th>Variable</th>
<th>Gender</th>
<th>Mean (SD or range)</th>
</tr>
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<tbody>
<tr>
<td>Height (cm)</td>
<td>Female</td>
<td>162.4 (4.61)</td>
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<td>Male</td>
<td>173.2 (4.42)</td>
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<td>Weight (kg)</td>
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<tr>
<td></td>
<td>Male</td>
<td>70.9 (5.74)</td>
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<td>BMI (kg m⁻²)</td>
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<tr>
<td></td>
<td>Male</td>
<td>23.6 (1.23)</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>Female</td>
<td>30.1 (24–45)</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>33.8 (24–44)</td>
</tr>
</tbody>
</table>

Fig 3 Movement of the CM anteriorly and laterally towards dependent side when changing from the supine to the lateral position with knees and hips flexed. Boxes show medians (Wilcoxon P<0.001) and 25th–75th percentiles, and whiskers show the range.
L2 (mode L1/L2 interspace), which is within the normally accepted range. In 27 volunteers, the CM did not move along the cranio-caudal axis with a change in body position; in three (10%), it moved cranially one-third of a vertebral segment (not significant).

We observed that the spinal nerve roots clustered symmetrically on either side of the CM in the posterior subarachnoid space when supine, but tended to shift in the same direction as the spinal cord tip (i.e. towards the anterior aspect of the dura and laterally towards the dependent side) in the lateral position (Figs 4 and 5).

**Discussion**

We evaluated movement of the spinal cord and related structures with changes in body position in 30 of 34 volunteers. We had been unable to obtain quantitative data for a power analysis and thought 30 a reasonable number on which to base a description, given that each subject acted as his/her control.

The dimensional constraints of the MRI scanner excluded taller and heavier volunteers (the tallest was 1.79 m and weighed 83 kg; the greatest BMI was 26.1) because they could not fit comfortably when lying laterally and fully flexed. The purpose of the cod-liver oil capsule was to provide a distal reference point from which to identify the vertebral bodies on subsequent scans confined to the lower thoracic and lumbar regions. Counting down from C1, rather than up from L5, is more accurate because common variations of lumbo-sacral anatomy can cause errors. We excluded movement of the marker between sequences obtained in the two positions by correlation with other
anatomical features (such as the origins of psoas, erector spinae, and diaphragmatic crura and the coeliac trunk, renal arteries, and inferior mesenteric artery from the aorta) on the high-resolution images.

In all volunteers, the vertebral level of the CM tip lay within the normal ranges obtained from previous studies in both cadavers and living subjects. Overall, this level did not change significantly on moving from the supine to the left lateral position with knees and hips flexed. However, we did observe cranial movement in three (10%) volunteers (one-third of a vertebral body in each). We also clearly demonstrated marked anterior shift of the CM tip in the left lateral position, with overall a lesser degree of shift towards the dependent side. Although anterior shift occurred in all volunteers, we observed no lateral movement in seven subjects (23%). The spinal nerve roots moved in a similar direction to the CM.

Shift of spinal structures with change of body position has been observed before in studies using MRI. However, in the larger studies, the positions adopted were not relevant to neuraxial blockade. Vernet and colleagues, for example, showed that in healthy children, the spinal cord consistently migrated anteriorly when prone, but did not quantify this. In a similar study of both adults and children, Witkamp and colleagues reviewed MR images from seven subjects and noted that the cauda equina lay symmetrically along the posterior aspect of the subarachnoid space in the supine position but moved to the dependent side when lateral. In three others, they further observed shift of the cauda equina to the anterior half of the subarachnoid space with leg flexion, creating a large space free of nerves posteriorly. The authors postulated that this might increase the safety margin during neuraxial blockade. Unfortunately, they neither quantified the shift nor noted the CM position.

In our larger study of 30 volunteers, we both confirmed consistent and significant anterior movement of the CM (6.3 mm; SD 2.15 mm) and associated nerve roots. Although we observed a statistically significant movement of the CM towards the lateral dependent side (mean 1.63 mm, SD 1.19 mm), this did not occur in seven subjects. The spinal cord is stabilized within the vertebral canal by dentate ligaments, nerve roots, and the filum terminale. The 21 or 22 paired dentate ligaments run along the lateral aspect of the cord. The most caudal pair lies between the T12 and the L1 nerve roots, continuing below as white lines on either side of the CM and forming part of the filum terminale. The dentate ligaments appear to have a greater stabilizing role in the cervical and upper thoracic regions but are sufficiently loose to allow movement of the spinal cord in an anterior or posterior direction when either prone or supine, respectively. As the dentate ligaments end at T11, the distal cord can move more freely. In our volunteers, we noted greater and more consistent anterior shift of the CM and cauda equina than laterally. Possible explanations include spinal cord tethering higher up by the dentate ligaments and the space occupying effect of the nerve roots, hindering marked lateral cord movement.

In conclusion, both the CM and the associated nerve roots shift consistently and significantly anteriorly when moving from the supine to the lateral position with knees and hips flexed (as during neuraxial blockade). This may provide a greater margin of safety during neuraxial blockade than would be predicted from our current knowledge of anatomy. However, the absence of significant cranial movement of the CM along the cranio-caudal axis still makes the spinal cord vulnerable.

Further developments in MRI and the use of open or upright scanners may allow comparison of the lateral with the sitting position in the future to define which position is the safest for patients during neuraxial blockade.

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