Morphometrical analysis of the thoracolumbar dural sac in sheep using computed assisted myelography

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Keywords
Animal model, ovine, dural sac, myelography, computed tomography

Summary
Objectives: Sheep are frequently used as animal models in experimental spinal injury studies. Therefore, extensive knowledge of ovine spinal dimensions is essential for experimental design and interpretation of results obtained in these trials. This study aimed to obtain quantitative morphometrical data of the thoracolumbar dural sac in sheep and determine the anatomical relationship between the dural sac and the vertebral canal.

Methods: Computed assisted myelography imaging was carried out in five adult German Black-Headed Mutton sheep under general anaesthesia. Transverse images were acquired with 2 mm slice thickness from the first thoracic to the sixth lumbar vertebrae. Sagittal and transverse diameters and the cross-sectional area of the dural sac and vertebral canal were measured. To determine the anatomical relationship between the dural sac and vertebral canal, the pedicle-dural sac distance (PPSD) and the epidural space as well as the SAC (available space for the dural sac) were calculated.

Results: Sagittal diameters of the dural sac ranged from 5.1 to 12.0 mm. Transverse diameters ranged from 5.6 to 12.2 mm. The dural sac area covered 45.9% and 49.0% of the thoracic and lumbar vertebral canal area. The PPSD in the lumbar vertebrae was up to 15.8% larger than in the thoracic ones. The dural sac area was significantly positively correlated with the transverse diameter and area of the vertebral canal.

Clinical significance: The lumbar vertebral canal contained more space for the dural sac, which seems to be safer for testing spinal implants.

Introduction
New spinal implants and surgical procedures have been developed and modified for surgical treatment of spinal instability as well as spinal cord injuries and therefore they should be tested before being accepted into clinical use (1). Animal models are most commonly used for such tests when they are available and provide more homogeneity when selected for age, breed, and sex than human specimens (2). Non-human primates provide an excellent model thanks to their analogy with humans, but are not cost-efficient; they require stringent controls and may be vectors of severe zoonotic diseases as well as a source of ethical concerns (3, 4). Cats, dogs and rats have also been used as animal models for research in spine and spinal cord trauma, however sheep are especially well accepted as an ethical animal model as they have a similar body weight to humans, and are sufficiently large to allow serial sampling and multiple experimental procedures (5-10). Furthermore, sheep have been reported to be a suitable model for human spinal research due to the similarity of the skeletal and vascular anatomy of both species (11).

In humans, the shape of the vertebral canal after injury, as determined by the sagittal-to-transverse diameter ratio, is predictive of neurological deficit, where the ratio of sagittal-to-transverse diameter at the level of injured spinal cord is significantly smaller in patients with a neurological deficit than in those without one (12). The vertebral canal area can be evaluated in different ways. The ratio of the sagittal...
diameter of the cervical canal to that of the vertebral body was first proposed as an indicator of the degree of developmental canal narrowing (13). With the development of diagnostic methods, other reliable means for assessing vertebral canal area were introduced, such as the measurement of the ratio between spinal canal area and vertebral body obtained from computed tomography (CT) images or computed assisted myelography. Computed assisted myelography has been found to be more sensitive than myelography for characterizing morphology of the spine in humans, horses, and dogs (14-18). The technique is considered to be particularly helpful for diagnosing spinal cord atrophy, spinal stenosis, and vertebral malformation-malarticulation (16, 19-23). Cross-sectional area measurements from CT images are a sensitive method for quantifying spinal components (24-27). The use of area ratios has been found to be a good means to help correct for differences in body sizes (26).

Despite the increasing use of the sheep as an animal model for human spinal research, no morphometrical computed tomographical studies related to the dural sac of the thoracolumbar spine in normal sheep were found at the time of this study. Therefore, the current study aimed to obtain quantitative morphometrical data of the thoracolumbar dural sac in sheep, and determine the anatomical relationship between the dural sac and surrounding osseous structures of the vertebral canal.

**Material and methods**

**Animals**

For the present study, five healthy female German Black-Headed Mutton sheep without history or clinical signs related to spinal diseases were included. The mean age of the sheep was 2.0 ± 0.4 years. The mean body weight was 80.6 ± 28.7 kg. This study was approved by the Animal Welfare Commission, Regional Office Leipzig (Landesdirektion Sachsen) (TVV-No. 14/03).

**Anaesthesia**

Each sheep was fasted for 24 hours and deprived of water for 12 hours before being premedicated with atropine sulphate (0.1 mg/kg), and a combination of butorphanol tartrate (0.1 mg/kg) and midazolam (0.2 mg/kg) was administered intravenously. Anaesthesia was induced with ketamine chlorhydrate (3 mg/kg) intravenously. After endotracheal intubation, anaesthesia was maintained with isoflurane delivered in oxygen through an endotracheal tube.

**Myelography technique**

After induction of general anaesthesia, the sheep were positioned in lateral recumbency on a radiographic table. The lumbar tap site was clipped and aseptically prepared. The most dorsocranial edge of the spinal process of the sixth lumbar (L6) vertebra was identified. Thereafter, a 8.9 cm, 22-G spinal needle was introduced through the skin on the midline at 90° on the midsagittal axis of the vertebral body with the bevel directed cranially. The needle was then slowly advanced until contact was made with the ventral floor of the vertebral canal and then retracted 2 mm before the stylet was removed to check the passive cerebrospinal fluid drip. To facilitate cerebrospinal fluid drip dripping through the needle hub, the jugular veins were compressed. One to 2 ml of CSF fluid was aspirated before injecting the contrast solution through a flexible extension tube connecting the needle and syringe. A dose of 0.45 ml/kg of non-ionic iodinate contrast media was injected slowly (about 2–3 minutes). The sheep were positioned at different positions to facilitate contrast media distribution in the subarachnoidal space then positioned on the CT scanner table for imaging. After imaging the sheep were kept under clinical observation for 72 hours.

**Computed tomography examination**

The sheep were positioned in dorsal recumbency with the hindlimbs flexed to minimize curvatures of the thoracolumbar spine and positioning aid tools were used to obtain a perpendicular position of the spine relative to the x-ray beam of the gantry. Contiguous slices were obtained from the cranial aspect of first thoracic vertebra (T1) to the caudal aspect of L6 with a multi-detector-row helical CT unit. Technical settings were 140 kV, 255 mAs, 0.75 second tube rotation and a pitch of 0.533. The data were reconstructed to transverse image series with 2 mm slice thickness using a high-frequency image reconstruction algorithm (bone). Multi-planar reformattting software was used as needed to reformat the transverse slices parallel to the cranial endplate of the vertebral body. Computed tomography images were transferred to a workstation and reviewed with picture archival and communication software, which allows for quantitative measurement of the distance and the area on CT images in DICOM format. From the transverse images series, a single CT image through the middle third of the vertebral body was selected for measuring. This level demonstrates individual features of each vertebra relative to the adjacent vertebra. Moreover, at this level the lamina and pedicles are completely surrounding the dural sac. For all measurements, images were displayed using a 2500 window width and 480 window level on the same workstation.

The parameters of the dural sac and vertebral canal included sagittal and transverse diameters and cross-sectional area (Figure 1). In order to depict the anatomical relationship between the dural sac and surrounding osseous structures, the pedicle-dural sac distance (PDS), epidural space areas, and available space for dural sac (SAC) were calculated. The PDS was defined as the distance between the axial border of the right/left pedicle and the lateral limit of the dural sac, which was
delineated with contrast solution. The PDSD was calculated by subtracting the distance between the ipsilateral border of the dural sac and the axial border of the contralateral pedicle from the transverse diameter of the vertebral canal. The epidural space area was calculated by subtracting the dural sac area from the vertebral canal area. The SAC was determined by subtracting the sagittal diameter of the dural sac from the sagittal diameter of the vertebral canal. All measurements were performed by the same operator (MM). Each parameter was measured three times and then six times in one sheep, to evaluate for the intraobserver error. There was at least a three-day interval between the measurements of each parameter.

Statistical analysis

Intraobserver reliability was calculated as the difference between three measurements obtained by the same operator. One-way analysis of variance and the Scheffe test were used to determine the differences between the values of the same parameter at the vertebral levels. The association between the different measurements was assessed using Pearson’s correlations. The level of significance was set at $p < 0.001$ and $r > 0.7$. All statistical tests were performed using SPSS software version 20 for Windows.

Results

Our analysis did not show any significant difference between measuring three and six times. Therefore, we chose to measure each parameter only three times. All sheep recovered well from the anaesthesia during the first 25 minutes after being disconnected from the anaesthetic machine. Four sheep were able to stand on all four limbs without assistance within one hour after the CT scan, whereas the fifth sheep stood after six hours and showed a mild lameness during the first 24 hours. It therefore received a single dose of meloxicam\(^\text{k}\) (0.5 mg/kg, IV) and recovered well.

For morphometrical analysis, each parameter was measured three times to minimize the intraobserver error, which made a total of 1995 readings for all parameters. Intraobserver variability was small as the average difference between three measurements for each vertebra was within 1 mm and 1 mm\(^2\) for cross-sectional area.

Detailed measurements of the sheep thoracolumbar dural sac and vertebral canal are shown in Table 1. The sagittal diameters of the dural sac for the T1 to L6 ranged from 5.1 mm to 12.0 mm (mean = 7.6 mm). The maximum mean sagittal diameter of the dural sac was observed at the level of the T1 vertebra (9.4 ± 1.6 mm) and the lowest was observed at T5 (6.0 ± 1.5 mm). For the transverse diameter, the values varied between 5.6 mm and 12.2 mm (mean = 7.6 mm). The minimum transverse diameter was seen at the T5 vertebral level (6.0 ± 1.5 mm) and the maximum at the T1 vertebral level (11.3 ± 0.7 mm). The mean cross-sectional area for the dural sac was 45.5 mm\(^2\) in the thoracic spine. This represented approximately 45.9% of the thoracic vertebral canal transverse area (mean = 107.2 mm\(^2\)). In the lumbar region, the mean transverse area for the dural sac was 51.6 mm\(^2\), which represented 49.0% of the vertebral canal area (mean = 117.1 mm\(^2\)). Significant differences ($p < 0.001$) were detected for each dimension of the dural sac between the vertebral levels (Table 1).

The maximum mean sagittal diameter of the vertebral canal over the entire thoracolumbar spine was found at T1 (15.4 ± 1.5 mm) and the minimum at T5 (8.8 ± 2.3 mm). The maximum transverse diameter was observed at T1 (23.3 ± 3.0 mm). The minimum transverse diameter was found at T9 (10.8 ± 0.8 mm). The mean vertebral canal area was 107.2 and 117.1 mm\(^2\) in the thoracic and lumbar region, respectively. Significant differences ($p < 0.001$) were observed within each parameter of the vertebral canal between the vertebral levels (Table 1).

There was no significant difference observed between the right and left PDSD. However, the dural sac tended to extend more to the left. The maximum mean PDSD was observed at the level of the T1 vertebra (4.4 ± 1.3 mm) and the lowest was observed at T6 (0.9 ± 0.2 mm). In the lumbar spine, the PDSD was 15.8% larger than in the thoracic vertebral (Table 1).

In the thoracic region, the SAC ranged from 2.2 to 6.0 mm (mean = 3.3 mm), with the greatest value at T1 (6.0 ± 1.2 mm) and lowest at T10 (2.4 ± 1.6 mm). Whereas in the lumbar region, SAC values ranged from 3.0 to 4.1 mm (mean = 3.3 mm), and were greatest at L6 (4.1 ± 0.8 mm).
mm) and lowest at L3 (3.0 ± 0.9 mm) (Table 1).

When vertebral levels were analysed individually, there were not any significant correlations found between dimensions of the dural sac and dimensions of vertebral components. When all segments (T1-L6) were analysed as a group, area ve.

Table 1  Morphometrical dimensions (mean and standard deviation) of the thoracolumbar vertebral canal and dural sac in five normal adult sheep.

<table>
<thead>
<tr>
<th>Vertebral level</th>
<th>TDS (mm)</th>
<th>SDS (mm)</th>
<th>ADS (mm²)</th>
<th>TVC (mm)</th>
<th>SVC (mm)</th>
<th>AVC (mm²)</th>
<th>PDSD (mm)</th>
<th>AES (mm²)</th>
<th>SAC (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>11.3 ± 0.7a</td>
<td>9.4 ± 1.6a</td>
<td>84.9 ± 12.3a</td>
<td>23.2 ± 3.0a</td>
<td>15.4 ± 1.5a</td>
<td>268.7 ± 12.2a</td>
<td>4.4 ± 1.3a</td>
<td>169.8 ± 42.1a</td>
<td>6.0 ± 1.2a</td>
</tr>
<tr>
<td>T2</td>
<td>8.7 ± 1.5cd</td>
<td>8.6 ± 1.7b</td>
<td>48.7 ± 3.5ab</td>
<td>14.5 ± 1.3bc</td>
<td>11.2 ± 1.0ab</td>
<td>124.6 ± 9.7bcd</td>
<td>2.2 ± 0.6bc</td>
<td>72.2 ± 13.0b</td>
<td>2.8 ± 1.1b</td>
</tr>
<tr>
<td>T3</td>
<td>7.5 ± 0.6bc</td>
<td>7.2 ± 0.4b</td>
<td>41.4 ± 2.0b</td>
<td>13.6 ± 1.3bc</td>
<td>10.8 ± 0.6b</td>
<td>109.4 ± 4.1cde</td>
<td>1.8 ± 0.5bc</td>
<td>65.7 ± 7.2bc</td>
<td>3.5 ± 0.4bd</td>
</tr>
<tr>
<td>T4</td>
<td>7.3 ± 0.6bc</td>
<td>6.5 ± 0.8c</td>
<td>42.8 ± 4.8b</td>
<td>12.0 ± 1.3c</td>
<td>10.1 ± 1.2b</td>
<td>93.5 ± 12.4a</td>
<td>1.6 ± 0.7b</td>
<td>51.0 ± 10.6a</td>
<td>3.6 ± 1.7ab</td>
</tr>
<tr>
<td>T5</td>
<td>6.0 ± 1.5c</td>
<td>6.0 ± 1.4b</td>
<td>38.5 ± 14.3b</td>
<td>10.8 ± 2.7cd</td>
<td>8.8 ± 2.3b</td>
<td>88.8 ± 6.7de</td>
<td>1.4 ± 0.7bc</td>
<td>45.2 ± 12.0b</td>
<td>3.3 ± 1.0b</td>
</tr>
<tr>
<td>T6</td>
<td>6.8 ± 0.4bd</td>
<td>6.3 ± 0.7b</td>
<td>41.1 ± 5.5b</td>
<td>11.1 ± 1.0cd</td>
<td>10.1 ± 0.7b</td>
<td>97.7 ± 10.1cde</td>
<td>0.9 ± 0.2c</td>
<td>49.9 ± 10.8b</td>
<td>3.8 ± 1.1ab</td>
</tr>
<tr>
<td>T7</td>
<td>6.9 ± 0.2bcd</td>
<td>6.1 ± 0.4b</td>
<td>41.5 ± 9.3b</td>
<td>11.1 ± 1.3cd</td>
<td>9.5 ± 1.1b</td>
<td>82.2 ± 15.6de</td>
<td>1.3 ± 0.6bc</td>
<td>41.7 ± 17.9b</td>
<td>3.3 ± 1.3ab</td>
</tr>
<tr>
<td>T8</td>
<td>6.9 ± 0.6bc</td>
<td>6.1 ± 0.5b</td>
<td>40.7 ± 6.8b</td>
<td>11.0 ± 1.1cd</td>
<td>9.7 ± 1.0b</td>
<td>79.0 ± 14.9de</td>
<td>1.2 ± 0.4bc</td>
<td>38.3 ± 17.5b</td>
<td>3.5 ± 1.2ab</td>
</tr>
<tr>
<td>T9</td>
<td>6.8 ± 0.5bc</td>
<td>6.2 ± 0.6b</td>
<td>40.0 ± 6.7b</td>
<td>10.8 ± 0.8cd</td>
<td>9.3 ± 1.3b</td>
<td>77.2 ± 14.5abc</td>
<td>1.1 ± 0.3bc</td>
<td>36.7 ± 16.9b</td>
<td>3.1 ± 1.5ab</td>
</tr>
<tr>
<td>T10</td>
<td>7.1 ± 0.3bc</td>
<td>6.6 ± 0.4b</td>
<td>35.7 ± 3.2b</td>
<td>11.5 ± 0.4cd</td>
<td>8.9 ± 1.2b</td>
<td>83.0 ± 13.5de</td>
<td>1.4 ± 0.3bc</td>
<td>38.3 ± 16.9b</td>
<td>2.4 ± 1.6bc</td>
</tr>
<tr>
<td>T11</td>
<td>6.9 ± 0.8bc</td>
<td>6.6 ± 0.3b</td>
<td>39.3 ± 7.7b</td>
<td>10.9 ± 0.9cd</td>
<td>9.5 ± 0.9b</td>
<td>84.9 ± 13.2de</td>
<td>1.1 ± 0.4bc</td>
<td>40.4 ± 18.4b</td>
<td>2.9 ± 0.8bc</td>
</tr>
<tr>
<td>T12</td>
<td>6.7 ± 0.4c</td>
<td>6.6 ± 0.3b</td>
<td>39.4 ± 8.9b</td>
<td>11.3 ± 0.9cd</td>
<td>9.2 ± 0.8b</td>
<td>90.0 ± 9.0de</td>
<td>1.4 ± 0.5bc</td>
<td>40.4 ± 16.1b</td>
<td>2.6 ± 0.9bc</td>
</tr>
<tr>
<td>T13</td>
<td>7.2 ± 0.4bc</td>
<td>6.3 ± 0.4b</td>
<td>39.4 ± 9.9b</td>
<td>12.2 ± 0.4cd</td>
<td>9.2 ± 0.5b</td>
<td>92.6 ± 8.0de</td>
<td>1.4 ± 0.2bc</td>
<td>48.1 ± 15.1b</td>
<td>2.9 ± 0.6bc</td>
</tr>
<tr>
<td>T14</td>
<td>6.8 ± 0.4bc</td>
<td>6.5 ± 0.7b</td>
<td>42.2 ± 9.5b</td>
<td>12.8 ± 0.6cd</td>
<td>9.1 ± 0.4b</td>
<td>92.4 ± 5.8abc</td>
<td>1.9 ± 0.2bc</td>
<td>49.4 ± 17.3b</td>
<td>2.5 ± 0.4bc</td>
</tr>
<tr>
<td>T15</td>
<td>7.0 ± 0.5bc</td>
<td>6.4 ± 0.5b</td>
<td>43.7 ± 11.9b</td>
<td>12.8 ± 0.5bc</td>
<td>9.6 ± 0.6b</td>
<td>103.1 ± 10.3cde</td>
<td>1.8 ± 0.6bc</td>
<td>51.7 ± 19.4b</td>
<td>3.2 ± 1.0bc</td>
</tr>
<tr>
<td>T16</td>
<td>7.1 ± 0.5bc</td>
<td>6.7 ± 0.3ab</td>
<td>45.6 ± 10.2b</td>
<td>12.9 ± 0.6bc</td>
<td>9.7 ± 0.6b</td>
<td>95.2 ± 8.3abc</td>
<td>1.7 ± 0.6bc</td>
<td>50.6 ± 22.7b</td>
<td>3.0 ± 0.9bc</td>
</tr>
<tr>
<td>T17</td>
<td>7.6 ± 0.6bc</td>
<td>7.2 ± 0.8b</td>
<td>54.1 ± 12.3b</td>
<td>13.6 ± 0.8bc</td>
<td>10.7 ± 1.9ab</td>
<td>105.4 ± 7.2de</td>
<td>1.8 ± 0.5bc</td>
<td>55.1 ± 21.0b</td>
<td>3.7 ± 1.3bc</td>
</tr>
<tr>
<td>T18</td>
<td>8.5 ± 1.3ab</td>
<td>7.2 ± 1.2ab</td>
<td>58.6 ± 18.9b</td>
<td>14.5 ± 2.7bc</td>
<td>10.6 ± 1.8b</td>
<td>139.7 ± 16.9bc</td>
<td>1.6 ± 0.4bc</td>
<td>64.8 ± 20.7b</td>
<td>3.7 ± 0.9bc</td>
</tr>
<tr>
<td>T19</td>
<td>10.0 ± 1.1bc</td>
<td>7.5 ± 1.2ab</td>
<td>60.4 ± 12.4b</td>
<td>19.1 ± 0.8d</td>
<td>11.6 ± 1.2ab</td>
<td>167.0 ± 8.9b</td>
<td>2.9 ± 0.6b</td>
<td>85.8 ± 28.2ab</td>
<td>4.1 ± 0.8bc</td>
</tr>
</tbody>
</table>

Values with different superscript letters in the same column are significantly different. TDS = transverse diameter of the dural sac; SDS = sagittal diameter of the dural sac; ADS = area of the dural sac; TVC = transverse diameter of the vertebral canal; SVC = sagittal diameter of the vertebral canal; AVC = area of the vertebral canal; PDSD = pedicle-dural sac distance; AES = area of the epidural space; SAC = space available for dural sac; T = thoracic; L = lumbar. ‘indicates p < 0.001.

Discussion

The current study aimed to obtain quantitative morphometrical data of the thoracolumbar dural sac in normal sheep using computed assisted myelography, and to determine the anatomical relationship between the dural sac and surrounding osseous structures of the vertebral canal.

The dural sac area covered 45.9% and 49.0% of the thoracic and lumbar vertebral canal transverse area and was significantly positively correlated with the transverse diameter and area of the vertebral canal. The PDSD in the lumbar vertebrae was up to 15.8% larger than in the thoracic ones.

The dural sac did not appear uniform in diameter owing to the normal widening of the dural sac in the most cranial thoracic and lumbar dural sac as a result of the bra-

chial and lumbosacral spinal intumescences, respectively. The variability of the transverse diameter of the dural sac with its cross-sectional area was more prominent than that of the sagittal diameter. This indicates that the transverse diameter is a more significant measurement for the cross-sectional area, and the most cranial thoracic and lumbar enlargements are more dependent on the transverse diameter than on the sagittal diameter. This finding was supported by those of other investigators who reported that cervical enlargement in humans is usually not visibly apparent on sagittal images because it is mainly present in the axial plane (28). Nonetheless, it may be seen on coronal images (28).

Transverse diameters of the vertebral canal were greater than sagittal diameters in all thoracolumbar vertebral levels. In CT
images, the epidural space was visible only in the lateral portions of the canal in the most thoracolumbar vertebral levels, particularly at the mid and caudal thoracic spine. Epidural space areas were calculated by subtracting the dural sac area from the vertebral canal area. Mean epidural space areas represented approximately 54.1% of the vertebral canal area for the thoracic spine and 51.0% for the lumbar spine.

In the current study, an attempt was made to define the anatomical relationships of the thoracolumbar osseous structures to the dural sac, which represented an important factor for spinal implants and surgical procedures planning. We measured the space between the dural sac and pedicles at all thoracolumbar vertebral levels. The results showed that the PDSD of lumbar vertebrae was up to 15.8% larger than that of thoracic vertebrae, meaning that the lumbar pedicles are safer for application of spinal implants, such as an intrapedicular screw, than the thoracic region. Furthermore, our data showed that PDSD space was smaller in the lumbar region (ranged from 1.6 mm to 2.9 mm) and that there were no significant differences among lumbar levels from L1 to L5. However at the L6 level, the space between the dural sac and pedicle was much wider, which means a spinal implant is safer to be tested at L6 than at other lumbar levels.

The SAC is recommended to be an effective indicator of spinal stenosis in human patients (29). The minimum SAC values in the lumbar region were greater than the SAC values of all of the thoracic vertebrae except T1. The clinical relevance of this finding is that the lumbar spine is safer than the thoracic region for application of spinal implants.

The myelogram protocol in this study was modified from the protocol used for large dogs (30). The post myelography complications we observed in one sheep were a delay in standing without assistance and mild lameness in the first 24 hours. Six attempts were needed in this sheep before the needle could be positioned in the subarachnoid space. The main reason for repeating puncture was the thick layer of subcutaneous adipose tissue (weight = 115 kg), which reduced the exact localisation of the landmarks, thus increasing the likelihood of causing more damage to the neural structures with each attempt.

The accuracy of the morphometrical study may be affected by several factors such as positioning, imaging settings, imaging parameters and post-processing, in particular the reconstruction algorithm and the reformatting parameters, as well as the mode of display (31, 32).

Dorsal recumbency is the position of choice for spine CT imaging because it ensures minimal respiratory movements of the spine and minimized curvatures of the spine. Therefore, the sheep were positioned in dorsal recumbency perpendicular to the x-ray beam. It is crucial to position the spine perpendicular to the x-ray beam of the gantry because the diameter and area dimensions of objects located in the transverse plane can be altered if they are not perpendicular to the scan plane (33). Decreasing slice thickness (2 mm in this study) reduces the amount of volume averaging artefact and thus improves spatial resolution, but it also increases the image noise. To keep the noise at an acceptable level, high mAs and wide window display should be used (34, 35). In the present study, the CT scanning settings were 255 mAs and 2500 Hounsfield units window width. The scanning parameters of this study are consistent with published spinal CT imaging protocol (35). Operator factors can also influence the measurements accuracy. In order to minimize operator factors, all measurements for this database were performed by a single observer (MM) (36). In a morphometric study of the canine lumbosacral spine, it was determined that the accuracy of transverse area measurements was lower than diameter measurements (26). This was considered to be most likely due to operator error related to irregular hand tracing of the regions of interest.

One limitation of this study was the small sample size. The use of only five animals was the lowest possible number to still comply with the rules of 3Rs (Replacement: use of non-animal methods; Reduction: reduce the number of animals used, and Refinement: improve animal welfare), but sufficient enough to provide reliable data (37). Furthermore, to overcome the problem of small sample size, significance for

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Correlations between the different dimensions of the vertebral canal and dural sac of the thoracolumbar vertebrae in five normal adult sheep.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TVC</td>
</tr>
<tr>
<td>Transverse diameter of the dural sac (TVC)</td>
<td>0.782*</td>
</tr>
<tr>
<td>Sagittal diameter of the dural sac (SDS)</td>
<td>0.616</td>
</tr>
<tr>
<td>Area of the dural sac (ADS)</td>
<td>0.726*</td>
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<tr>
<td>Transverse diameter of the dural sac (TDS)</td>
<td>0.781*</td>
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<tr>
<td>Sagittal diameter of the vertebral canal (SVC)</td>
<td>0.890*</td>
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<tr>
<td>Area of the vertebral canal (AVC)</td>
<td>0.796*</td>
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<tr>
<td>Pedicle-dural sac distance (PDSD)</td>
<td>0.727*</td>
</tr>
<tr>
<td>Area of the epidural space (AES)</td>
<td>0.558</td>
</tr>
</tbody>
</table>
| Space available for dural sac (SAC) | *

* indicates that r >0.7 and p <0.001.
the correlation analysis was set using a high r-value (>0.7) and a low p-value (<0.001).

In conclusion, this study provides a comprehensive quantitative morphometric database for the sheep thoracolumbar dural sac and its relation to ossous structures of the vertebral canal. Findings from this study indicate that the lumbar vertebral canal has a greater space for the dural sac than the thoracic vertebrae. Based on this finding, we recommend using lumbar vertebrae for preclinical testing of spinal implants, such as the intrapedicular screw, and to avoid neural structure injuries, when sheep are used as an animal model.

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Conflict of interest

The authors declare that there is no conflict of interest.

References


