Agreement between computed tomography, magnetic resonance imaging, and surgical findings in dogs with degenerative lumbosacral stenosis

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Objective—To assess the extent of agreement between computed tomography (CT), magnetic resonance imaging (MRI), and surgical findings in dogs with degenerative lumbosacral stenosis.

Design—Observational study.

Animals—35 dogs with degenerative lumbosacral stenosis.

Procedures—Results of preoperative CT and MRI were compared with surgical findings with respect to degree and location of disk protrusion, position of the dural sac, amount of epidural fat, and swelling of spinal nerve roots.

Results—A lumbosacral step was seen on radiographic images from 22 of 35 (63%) dogs, on CT images from 23 of 35 (66%) dogs, and on MR images from 21 of 35 (60%) dogs. Most dogs had slight or moderate disk protrusion that was centrally located. There was substantial or near perfect agreement between CT and MRI findings in regard to degree of disk protrusion (kappa, 0.88), location of disk protrusion (0.63), position of the dural sac (0.89), amount of epidural fat (0.72), and swelling of spinal nerve roots (0.60). The degree of agreement between CT and surgical findings and between MRI and surgical findings was moderate in regard to degree and location of disk protrusion (kappa, 0.44 to 0.58) and swelling of spinal nerve roots (0.40 and 0.50).

Conclusions and Clinical Relevance—Results indicate that there is a high degree of agreement between CT and MRI findings in dogs with degenerative lumbosacral stenosis but that the degree of agreement between diagnostic imaging findings and surgical findings is lower. (J Am Vet Med Assoc 2006;229:1924–1929)

Degenerative lumbosacral stenosis is the most common cause of compression of the cauda equina in dogs. The condition is a result of various degenerative changes involving the bone and soft tissues surrounding the cauda equina, such as intervertebral disk protrusion, hypertrophy of the dorsal longitudinal liga-

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assess the extent of agreement between CT, MRI, and surgical findings in dogs with degenerative lumbosacral stenosis.

Materials and Methods

Dogs—Thirty-five client-owned dogs with degenerative lumbosacral stenosis treated at the Department of Clinical Sciences of Companion Animals of Utrecht University were included in the study. In all dogs, the diagnosis had been confirmed on the basis of physical examination, radiographic, CT, MRI, and surgical findings. Dogs with other lumbosacral diseases, such as diskospondylitis, neoplasia, and traumatic injuries, were excluded.

Diagnostic imaging—In all dogs, radiography, CT, and MRI were performed prior to surgery. For these procedures, dogs were premedicated with medetomidine (100 μg/kg [45.5 μg/lb], IV) and anesthetized with propofol (1 to 2 mg/kg [0.45 to 0.9 mg/lb], IV); anesthesia was maintained with isoflurane. Monitoring consisted of electrocardiography; pulse oximetry, capnography; and measurement of body temperature.

Lateral and ventrodorsal radiographic views of the lumbosacral region were obtained. For the ventrodorsal view, the pelvic limbs were extended caudally.

Computed tomography was performed with the dogs in sternal recumbency with the pelvic limbs extended to the same degree as during radiography. Images were obtained with a third-generation CT scanner (20 dogs) with exposure settings of 120 kV and 220 mA and a scan time of 9 seconds or with a single-slice helical CT scanner (15 dogs) with exposure settings of 120 kV and 360 mA and a scan time of 1 second. Contiguous 2-mm-thick slices were obtained from the most caudal lumbar vertebra to the most caudal sacral vertebra. Transverse images were obtained with both bone and soft tissue window settings. Sagittal images were reconstructed from the transverse images.

Magnetic resonance imaging was also performed with the dogs in sternal recumbency with the pelvic limbs extended caudally to the same degree as during radiography. Images were obtained with a 0.2-Tesla open magnet. T1-weighted transverse and sagittal images were obtained with a repetition time of 510 to 624 milliseconds and an echo time of 26 milliseconds. T2-weighted sagittal images were obtained with a repetition time of 3,835 to 4,450 milliseconds and an echo time of 117 milliseconds. Pixel sizes of 0.95 × 0.71 mm and 0.86 × 0.59 mm were used for sagittal and transverse images, respectively. Contiguous 3-mm-thick slices were obtained.

Surgical procedure—Dorsal laminectomy was performed in all dogs by a single individual (BPM). Dogs were positioned in sternal recumbency with the caudal lumbar and lumbosacral portions of the spine in a neutral position, the pelvic limbs in a frog-leg position, and the tarsal joints level with the ischiatric tuberosities. The caudal portion of the lamina of L7 and the cranial portion of the lamina of S1 were removed with a high-speed bur and bone punches. The degree (none or minimal, slight, moderate, or severe) and location (left, right, or central) of disk protrusion within the spinal canal, position of the dural sac (left, right, or central), amount of epidural fat (absent, reduced, normal, or abundant), and swelling of the nerve roots (none, left, right, or bilateral) were recorded. Dorsal fenestration and partial disectomy were performed when moderate to severe compression was found; swab specimens of the disk space were submitted for bacteriologic culture after fenestration. In some cases, biopsy specimens were submitted for histologic examination. A free autogenous fat graft was placed at the laminectomy site prior to closure to prevent connective tissue adhesions, and the incision was closed routinely.

Carprofen and amoxicillin-clavulanic acid were administered for 14 days after surgery. The dogs were restricted to short walks on a leash for the first 6 weeks after surgery, followed by a gradual increase in physical activity during the subsequent 6 weeks.

Assessing agreement of CT, MRI, and surgical findings—Radiographs (n = 32), CT images (35), and MR images (35) were reviewed by one of the authors (NS) without prior knowledge of surgical findings. Radiographs were examined for evidence of lumbosacral step formation, downward elongation of the sacral lamina into the vertebral canal, spondylosis deformans, transitional lumbosacral segments, narrowing of the lumbosacral intervertebral disk space, and presence of the vacuum phenomenon. The CT and MR images of the L6-7 and L7-S1 disk spaces were examined for evidence of lumbosacral step formation, spondylosis deformans, and presence of the vacuum phenomenon.

On CT and MR images, degree of disk protrusion was scored on the basis of maximal percentage of the spinal canal obstructed by the bulging disk on transverse and sagittal images (no or minimal obstruction, slight [< 25%] obstruction, moderate [25% to 50%] obstruction, or severe [> 50%] obstruction). The location of disk protrusion within the spinal canal was defined as left, right, or central, as was the position of the dural sac. The amount of epidural fat covering the dural sac and cauda equina was scored (absent, reduced, normal, or abundant), as was the presence of swelling of the nerve roots (none, left, right, or bilateral). On MR images, the degree of disk degeneration was graded on the basis of relative loss of signal intensity of the nucleus pulposus on sagittal T2-weighted images (normal signal, partial loss, or complete loss).

On the lateral radiographic projection and sagittal CT and MR images, the lumbosacral step was measured as the distance between a horizontal line drawn level with the floor of the spinal canal in the last lumbar vertebra and a second horizontal line drawn level with the floor of the spinal canal in the first sacral vertebra, halfway between these 2 vertebrae (Figure 1). For the radiographic projections, measurements were obtained with a Vernier caliper accurate to 0.1 mm and were corrected for magnification. For the CT and MR images, measurements were obtained with dedicated software. The lumbosacral canal ratio was calculated as the ratio between the height of the spinal canal for the first sacral vertebra and the height of the spinal canal for the last lumbar vertebra.
Statistical analysis—Data analysis was performed with standard software. Because values for the lumbosacral canal ratio were not normally distributed, the Friedman test followed by the Wilcoxon signed rank test was used to compare lumbosacral canal ratios obtained by means of radiography, CT, and MRI. For the Friedman test, a value of $P < 0.05$ was considered significant. For the Wilcoxon signed rank tests, a Bonferroni correction was performed. Thus, a value of $P < 0.016$ was considered significant for pairwise comparisons.

The kappa test was used to test the extent of agreement between CT, MRI, and surgical findings. A weighted kappa test was used for categoric data for which it could be assumed that all results that were identical were in partial agreement (ie, degree and location of disk protrusion, amount of epidural fat, and swelling of nerve roots). A simple (unweighted) kappa test was used for categoric data for which it could be assumed that all results that were not identical were in disagreement (ie, position of the dural sac). Kappa values $< 0.2$ were interpreted as slight agreement, values $0.2$ but $< 0.4$ were interpreted as fair agreement, values $0.4$ but $< 0.6$ were interpreted as moderate agreement, values $0.6$ but $< 0.8$ were interpreted as substantial agreement, and values $> 0.8$ were interpreted as near perfect agreement.

**Results**

Signalment and clinical signs—The 35 dogs included in the study consisted of 25 males (12 sexually intact and 13 neutered) and 10 females (5 sexually intact and 5 neutered). There were 10 German Shepherd Dogs, 7 Labrador Retrievers, 3 Golden Retrievers, 3 Border Collies, 2 Weimaraners, 1 Belgian Shepherd, 1 Schnauzer, 1 Great Dane, 1 Newfoundland, 1 German Longhaired Pointer, 1 Bearded Collie, 1 Leonberger, 1 American Staffordshire Terrier, 1 Dutch Partridge dog, and 1 mixed-breed dog. Mean ± SD body weight was $35.2 ± 11.0$ kg (77.4 ± 24.2 lb; range, 14.0 to 72.2 kg [30.8 to 158.8 lb]), and mean age was $5.6 ± 2.2$ years (range, 1.3 to 10.8 years). The dogs included 28 companion animals, 2 of which also performed agility; 1 show and breeding dog; 2 working (rescue and hunting) dogs; and 4 assistance dogs.

Thirty-three (94%) dogs had a history of reluctance to rise, $32 (91\%)$ had signs of pain when pressure was placed over the lumbosacral region, $29 (83\%)$ had pelvic limb lameness (8 bilateral and 21 unilateral), 26 (74\%) had signs of caudal lumbar pain, 24 (69\%) had a history of difficulty sitting, 24 (69\%) had signs of pain during extension of the caudal lumbar region, 22 (63\%) had a history of reluctance to jump, 21 (60\%) had pelvic limb paresis, 15 (43\%) had a history of difficulty climbing stairs, 9 (26\%) had atrophy of the pelvic limb musculature, 6 (17\%) had an abnormal gait, 6 (17\%) had signs of pain when defecating, 4 (11\%) had urinary incontinence, 3 (9\%) had hypotonia of the tail, and 2 (6\%) had signs of pain on extension of the tail.

Imaging and surgical findings—Radiography revealed abnormalities in 26 of $32 (81\%)$ dogs. Radiographic findings included lumbosacral step formation (22/32 [69\%]), spondylosis deformans at the lumbosacral junction (16 [50\%]), downward elongation of the sacral lamina into the vertebral canal (10 [31\%]), narrowing of the intervertebral disk space (4 [12.5\%]), vacuum phenomenon (3 [9\%]), and transitional lumbosacral vertebra (2 [6\%]).

**Table 1—Computed tomography, MRI, and surgical findings in 35 dogs with degenerative lumbosacral stenosis.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>CT</th>
<th>MRI</th>
<th>Surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of disk protrusion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None or minimal</td>
<td>5 (14)</td>
<td>5 (14)</td>
<td>3 (9)</td>
</tr>
<tr>
<td>Slight</td>
<td>14 (40)</td>
<td>13 (37)</td>
<td>12 (34)</td>
</tr>
<tr>
<td>Moderate</td>
<td>10 (29)</td>
<td>9 (26)</td>
<td>13 (37)</td>
</tr>
<tr>
<td>Severe</td>
<td>6 (17)</td>
<td>8 (23)</td>
<td>7 (20)</td>
</tr>
<tr>
<td>Location of disk protrusion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>2 (6)</td>
<td>3 (9)</td>
<td>2 (6)</td>
</tr>
<tr>
<td>Right</td>
<td>4 (11)</td>
<td>3 (9)</td>
<td>6 (17)</td>
</tr>
<tr>
<td>Central</td>
<td>29 (83)</td>
<td>29 (83)</td>
<td>27 (77)</td>
</tr>
<tr>
<td>Position of dural sac</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>7 (20)</td>
<td>7 (20)</td>
<td>2 (6)</td>
</tr>
<tr>
<td>Right</td>
<td>7 (20)</td>
<td>7 (20)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Central</td>
<td>21 (60)</td>
<td>21 (60)</td>
<td>33 (94)</td>
</tr>
<tr>
<td>Amount of epidural fat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absent or reduced</td>
<td>9 (26)</td>
<td>9 (26)</td>
<td>14 (40)</td>
</tr>
<tr>
<td>Normal</td>
<td>26 (74)</td>
<td>26 (74)</td>
<td>18 (51)</td>
</tr>
<tr>
<td>Abundant</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>3 (9)</td>
</tr>
<tr>
<td>Swelling of spinal nerve roots</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>16 (46)</td>
<td>17 (49)</td>
<td>16 (46)</td>
</tr>
<tr>
<td>Left</td>
<td>5 (14)</td>
<td>7 (20)</td>
<td>3 (9)</td>
</tr>
<tr>
<td>Right</td>
<td>4 (11)</td>
<td>4 (11)</td>
<td>4 (11)</td>
</tr>
<tr>
<td>Bilateral</td>
<td>10 (29)</td>
<td>7 (20)</td>
<td>12 (34)</td>
</tr>
</tbody>
</table>

Lumbosacral step formation was identified on CT images from 23 of the 35 (66\%) dogs, spondylosis deformans at the lumbosacral junction was identified in 14 (40\%), and the vacuum phenomenon was identified in 10 (29\%). Lumbosacral disk protrusion was identified on CT images from 30 of the 35 (86\%) dogs and was most often classified as slight or moderate and central (Table 1; Figures 2 and 3). Abnormal material in the vertebral canal resembling calcified disk material was observed on CT images from 4 (11\%) dogs.

Lumbosacral step formation was identified on MR images from 21 of the 35 (60\%) dogs, and spondylosis deformans at the lumbosacral junction was identified in 14 (40\%); the vacuum phenomenon was not identified in any dog. Lumbosacral disk protrusion was identified on MR images from 30 of the 35 (86\%) dogs and was most often classified as slight or moderate and central (Figure 4). Relative loss of signal intensity of the nucleus pulposus at the L7-S1 disk space was seen on sagittal T2-weighted images from 28 of the 35 (80\%).
dogs (partial loss, 10; complete loss, 18). Concurrent loss of signal intensity of the nucleus pulposus at the L6-7 disk space was seen in 5 of the 28 (18%) dogs.

Mean ± SD lumbosacral step was 2.25 ± 1.20 mm on radiographs, 2.08 ± 1.24 mm on CT images, and 2.24 ± 1.37 mm on MR images. Mean lumbosacral canal ratio was 0.69 ± 0.08 (range, 0.50 to 0.90) on radiographs, 0.79 ± 0.09 (range, 0.60 to 0.90) on CT images, and 0.88 ± 0.09 (range, 0.70 to 1.10) on MR images (in 1 dog, the height of the spinal canal for the first sacral vertebra was greater than the height of the spinal canal for the last lumbar vertebra, yielding a ratio > 1). Lumbosacral canal ratios measured on radiographs were significantly (P < 0.016) lower than ratios measured on CT and MR images.

Surgical findings during dorsal laminectomy included disk protrusion (32 [91%]), an absence of or reduction in the amount of epidural fat covering the dural sac (14 [40%]), and swelling of the spinal nerve roots (19 [54%]). hypertrophy of the ligamentum flavum was identified in 7 (20%) dogs. Dorsal fenestration and partial diskectomy was performed in 17 (40%) dogs. Disk material was collected from 16 dogs and submitted for bacterial culture, and results of bacterial culture were positive in 5 of the 16. Organisms that were isolated included Bacillus spp, Micrococcus spp, Clostridium perfringens, Staphylococcus intermedius, and mixed bacterial species. Follow-up (6 months after surgery) information was available for 32 of the 35 (91%) dogs. Twenty of the 32 (63%) dogs were reportedly normal, 10 (31%) had residual pelvic limb lameness, and 2 (6%) had not improved.

There was substantial or near perfect agreement between CT and MRI findings in regard to degree of disk protrusion, location of disk protrusion, position of the dural sac, amount of epidural fat covering the dural sac, and swelling of spinal nerve roots (Table 2). In contrast, the extent of agreement between CT and surgical findings and between MRI and surgical findings

<table>
<thead>
<tr>
<th>Variable</th>
<th>CT versus MRI</th>
<th>CT versus surgery</th>
<th>MRI versus surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of disk protrusion</td>
<td>0.88 ± 0.05</td>
<td>0.55 ± 0.10</td>
<td>0.52 ± 0.10</td>
</tr>
<tr>
<td>Location of disk protrusion</td>
<td>0.64 ± 0.11</td>
<td>0.56 ± 0.10</td>
<td>0.44 ± 0.13</td>
</tr>
<tr>
<td>Position of dural sac</td>
<td>0.89 ± 0.07</td>
<td>0.19 ± 0.12</td>
<td>0.19 ± 0.12</td>
</tr>
<tr>
<td>Amount of epidural fat</td>
<td>0.72 ± 0.13</td>
<td>0.28 ± 0.18</td>
<td>0.18 ± 0.13</td>
</tr>
<tr>
<td>Swelling of spinal nerve roots</td>
<td>0.60 ± 0.12</td>
<td>0.40 ± 0.14</td>
<td>0.50 ± 0.12</td>
</tr>
</tbody>
</table>

*Weighted kappa values. †Simple (unweighted) kappa values.
was only moderate for the degree of disk protrusion, location of disk protrusion, and swelling of spinal nerve roots and was only fair or slight in regard to position of the dural sac and amount of epidural fat covering the dural sac.

**Discussion**

Results of the present study indicate that there is a high degree of agreement between CT and MRI findings in dogs with degenerative lumbosacral stenosis. However, the degree of agreement between diagnostic imaging findings and surgical findings was only slight to fair.

In dogs with degenerative lumbosacral stenosis, compression of the cauda equina will be exacerbated when the pelvic limbs are extended caudally and partially relieved when the pelvic limbs are flexed. For this reason, the pelvic limbs of the dogs in the present study were extended caudally during CT and MRI. During surgery, however, dogs were positioned differently, with the pelvic limbs in a frog-leg position and the lumbosacral portion of the spine in a neutral position to relieve tension on the fascia and muscle, facilitating the surgical approach. The moderate correlation that was found between imaging and surgical findings may reflect, in part, the difference in positioning of the dogs during imaging versus surgery.

For dogs in the present study, mean lumbosacral step was 2.25 mm on radiographic images, 2.08 mm on CT images, and 2.24 mm on MR images. In contrast, authors of a previous study found that a lumbosacral step was clinically relevant if it was > 4 mm. Findings of the present study, therefore, suggest that a lumbosacral step as small as 2 mm may be clinically relevant, particularly when seen in combination with disk protrusion. However, the relevance of the lumbosacral step itself should be investigated further.

Mean lumbosacral canal ratio was 0.79 on CT images and 0.88 on MR images from dogs in the present study, and the ratio was > 0.50 in all dogs. In previous studies, a lumbosacral canal ratio ≤ 0.5 was identified as evidence of primary spinal canal stenosis causing cauda equina syndrome. Findings in the present study suggest that in dogs with degenerative lumbosacral stenosis, a canal ratio > 0.5 may be clinically relevant, particularly when seen in combination with disk protrusion.

In the present study, downward elongation of the sacral lamina into the vertebral canal was seen radiographically in 10 of 32 (31%) dogs. Nine of these 10 dogs also had lumbosacral step formation. Elongation of the sacral lamina may contribute to cauda equina compression, especially when disk protrusion and ventral subluxation of the sacrum (ie, a lumbosacral step) are also present.

Transitional lumbosacral vertebrae may predispose to other lumbosacral abnormalities that cause signs of caudal lumbar pain. In particular, transitional lumbosacral vertebrae may result in a weakening of sacrolilac attachments and may contribute to premature disk degeneration. They may, therefore, play a role in the development of lumbosacral instability and cauda equina compression. However, only 2 of 32 (6%) dogs in the present study had transitional lumbosacral vertebrae.

The vacuum phenomenon has previously been associated with degenerative disk disease. In the present study, vacuum phenomenon was observed in CT images from 10 of the 35 (29%) dogs but was not seen on MR images from any of the dogs. This may be explained by the fact that contrast between gas and bone is much lower on MR images than on CT images. Degenerative changes of the disk were found on T2-weighted sagittal MR images in 28 of 35 (80%) dogs. Disk degeneration is characterized by a decreased and altered proteoglycan concentration associated with loss of water from the nucleus pulposus. This altered water content leads to decreased signal intensity on T2-weighted MR images.

One advantage of CT versus MRI is a greater ability to discriminate between bone and calcified soft tissue structures versus gas opacities. However, it is difficult to distinguish soft tissue structures from the cauda equina. Advantages of MRI versus CT include greater soft tissue contrast; excellent visualization of nerve roots, intervertebral disks, and ligaments; detection of disk degeneration; lack of ionizing radiation; and ability to acquire images in multiple planes. However, a limitation of the open MRI scanner used in the present study was the low magnetic field strength, which resulted in limited spatial resolution.

There was substantial to near perfect agreement between CT and MRI findings in the present study but only slight to fair agreement between imaging and surgical findings. In part, this may have been attributable to difficulties in assessing degree of disk protrusion, distribution of epidural fat, and spinal nerve root swelling during surgery. In addition, differences in positioning of the dog could have affected the appearance during surgery. Loss of epidural fat at the location of disk protrusion in dogs with degenerative lumbosacral stenosis can create a silhouetting effect on CT and MR images, and protruded disk material may be difficult to distinguish from the dural sac and adjacent nerve roots. Thus, despite the high degree of agreement between CT and MRI findings, grading of characteristics for both imaging techniques was difficult in some cases. Both CT and MRI can provide valuable information regarding soft tissue structures in the vertebral canal, and both transverse and sagittal CT and MR images were useful for evaluating disk protrusion and cauda equina compression.

Twenty of the 32 (63%) dogs for which follow-up information was available were reportedly normal 6 months after surgery, and an additional 10 (31%) dogs only had residual pelvic limb lameness. Although pain relief can be expected within days after surgery because of relief of the compression on the cauda equina and nerve roots, the healing of neural tissue may require more time. Decompressive surgery has been reported to be effective in patients with degenerative lumbosacral stenosis. Although none of the dogs in the present study had radiographic signs of diskospondylitis, results of bacterial culture of disk swab specimens were positive in 5 dogs. *Staphylococcus intermedius* has been recovered from patients with diskospondylitis, but the other organisms that were isolated may have been a result of contamination.
In conclusion, findings of the present study suggest that a lumbosacral step as small as 2 mm and a lumbosacral canal ratio > 0.5 may be clinically relevant, particularly in dogs with disk protrusion, and that radiography, CT, and MRI were equally capable of detecting the lumbosacral step formation. There was excellent agreement between CT and MRI findings but only slight to fair agreement between diagnostic imaging and surgical findings.

c. Magnetom Open Viva, Siemens AG, Munich, Germany.
d. SPSS for Windows, version 11.0, SPSS Inc, Chicago, Ill.

References