Thoracolumbar IVD extrusion is the most common cause of extradural spinal cord compression in small-breed dogs.1,2 The resulting displacement of nuclear material into the spinal canal causes signs of pain and neurologic deficits that can range from loss of conscious proprioception of the hind limbs to bilateral paralysis with loss of deep pain sensation.3 Because most extrusions are lateral or ventrolateral relative to the spinal cord, definitive circumferential localization is essential to guide surgical decompression by use of hemilaminectomy or minihemilaminectomy.4–6 Various imaging modalities, including radiography, myelography, CT, and MRI, have been used to identify the affected disk space and the circumferential localization of extruded IVD material in dogs. Survey radiography and myelography are the most widely accessible diagnostic modalities. Myelography has a reported diagnostic accuracy of 72% to 97% for determining the site and side of extrusion but has been criticized for its invasiveness, potential adverse effects, and technical difficulty.4,7–9

### Abbreviations

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<th>Abbreviation</th>
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<tr>
<td>CI</td>
<td>Confidence interval</td>
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<td>FSE</td>
<td>Fast spin echo</td>
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<td>Gd-DTPA</td>
<td>Gadolinium diethylenetriaminepentaacetic acid</td>
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<td>GRE</td>
<td>Gradient echo</td>
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<td>IVD</td>
<td>Intervertebral disk</td>
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<td>MR</td>
<td>Magnetic resonance</td>
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<td>T1W</td>
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<td>T2W</td>
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<td>TE</td>
<td>Echo time</td>
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Magnetic resonance imaging is currently considered the imaging method of choice for evaluation of degenerative disk disease and spinal cord injury in humans. The procedure is noninvasive and produces high-resolution multiplanar images of the IVD, spinal cord parenchyma, subarachnoid and epidural spaces, nerve roots, and associated soft tissue structures. It does not expose the patient to radiation or require intrathecal injection of contrast medium.

Several studies have compared the usefulness of MRI and myelography to diagnose IVD herniation in humans and dogs. In a study in humans, MRI was shown to be more reliable than myelography for the diagnosis of unilateral single-disk herniation, whereas myelography identified the active site of compression in 12 of 53 patients with midline multilevel lumbar disk herniations. In previous studies in dogs, MRI was determined to be superior to myelography for differentiation of extradural hemorrhage from extradural IVD material or spinal cord swelling. Although investigators of one study reported the use of lateral myelography as an anatomic control for MRI in four healthy dogs and authors of another study performed myelography as a control for short-duration MRI in three patients with suspected IVD disease, comparison of myelography and multisequence MRI in a series of clinical patients has not been investigated in veterinary medicine.

Objectives of the study reported here were to determine accuracy, intermethod agreement, and interobserver agreement for multisequence MRI and 2-view orthogonal myelography in the diagnosis and localization of naturally occurring first-time thoracolumbar IVD extrusion in small-breed dogs.

Materials and Methods

**Animals**—Small-breed dogs (< 20 kg [44 lb]) recognized as being predisposed to IVD extrusion were included in the study. The dogs were evaluated at the Ontario Veterinary College Teaching Hospital for suspected first-time IVD extrusion at the T10 to L6 spinal cord segments between September 1, 2004, and March 31, 2007. Dogs that had undergone previous spinal surgery or had extrusions in other spinal cord segments were excluded.

Neurologic signs were evaluated and graded on a scale of 1 to 5 as previously described. The IVD extrusion sites were localized between T10 and L6 spinal cord segments by a board-certified neurologist or neurology resident. Diagnostic imaging including multisequence MRI and 2-view lumbar myelography was performed in dogs under general anesthesia with a 22-gauge spinal needle of appropriate length advanced to the ventral subarachnoid space at L5-6. Iohexol (0.33 to 0.5 mL/kg [0.15 to 0.23 mL/lb]) was injected. Fluoroscopy was used to direct needle placement and confirm subarachnoid contrast flow. If epidural enhancement occurred with lumbar puncture or a lower lumbar extrusion was anticipated, the L6-L7 or cerebellomedullary cistern was used for intrathecal injections. Ventrodorsal and lateral radiographic projections of the entire thoracolumbar vertebral column were obtained immediately after a sufficient amount of iohexol was injected to provide contrast columns to delineate the site of compression with a maximum dose of 0.5 mL/kg. Site of extrusion was determined by use of lateral and ventrodorsal projections, and side of extrusion was determined by use of the ventrodorsal projection.

**Anesthesia**—Protocols for induction of general anesthesia were selected at the attending clinician’s discretion. Dogs were intubated, and anesthesia was maintained with isoflurane in oxygen. Intravenous fluids were administered during each general anesthetic procedure at 10 mL/kg/h (4.5 mL/lb/h) for imaging and surgical decompression. Dogs were allowed to recover from anesthesia and monitored in the intensive care unit for ≥ 24 hours after anesthetic procedures.

**MRI**—Dogs were positioned in dorsal recumbency on the padded surface of a 1.5-T MRI unit with an 8 channel-phased array surface coil, and T1W FSE, T2W FSE, GRE, short tau inversion recovery, and contrast-enhanced T1W FSE images were obtained. The contrast agent, Gd-DTPA (0.1 mmol/kg [0.05 mmol/lb], IV), was administered immediately prior to repeating the T1W transverse and sagittal FSE sequences in dogs that had this procedure performed. The flip angle of GRE images was 20°.

Sagittal and transverse images were obtained with fields of view of 22 and 12 cm, respectively. Sagittal views were obtained from the level of T9 to the sacrum with a 2-mm slice thickness and T1W (TR, 400 to 700 milliseconds; TE, 11.9 to 19.5 milliseconds), T2W (TR, 2,800 to 5,000 milliseconds; TE, 85.1 to 94.4 milliseconds), and Gd-DTPA–enhanced T1W (TR, 450 to 617 milliseconds; TE, 9.2 to 18.7 milliseconds) sequences. Transverse images were obtained with 3-mm slice thickness through each IVD between T9 and S1 by use of T1W (TR, 450 to 750 milliseconds; TE, 7.2 to 13.4 milliseconds), T2W (TR, 3,200 to 6,100 milliseconds; TE, 81.2 to 93.3 milliseconds), GRE (TR, 400 to 650 milliseconds; TE, 9.7 to 15 milliseconds), and Gd-DTPA–enhanced T1W (TR, 450 to 730 milliseconds; TE, 8.8 to 13.4 milliseconds) sequences.

**Myelography**—When possible, myelography was performed immediately after MRI to avoid a potential enhancement effect of iodinated contrast medium on T1W images. Following orthogonal survey radiographs of the entire vertebral column, lumbar spinal puncture was performed with a 22-gauge spinal needle of appropriate length advanced to the ventral subarachnoid space at L5-6. Iohexol (0.33 to 0.5 mL/kg [0.15 to 0.23 mL/lb]) was injected. Fluo-
sion was typically made on the basis of results of MRI. Subjective descriptions of the quantity, composition, and circumferential location (ie, right, left, or ventral relative to the spinal cord) of the extradural material and gross appearance of the dura were recorded in the surgical records. A bilateral procedure was performed when IVD material was not retrieved during the initial surgical approach. Surgical confirmation of IVD extrusion was considered the gold standard for the determination of site and side of lesions. Dogs without evidence of extradural compression on MRI and myelographic images did not undergo surgical exploration. All dogs received cefazolin (22 mg/kg [10.0 mg/lb], IV) during surgical preparation and every 90 minutes during surgery.

Review of MRI and myelographic images—Six months after the final dog was enrolled in the study, MRI and myelographic images were compiled and the identification markers were removed. The images were independently reviewed by 3 of the authors (a radiologist [SGN], a surgeon [BAB], and a final-year surgical resident [ASB]) who had experience with MRI and myelography techniques. The reviewers were blinded to patient identification and clinical information. All MR images from the T9-10 disk space to the L5-6 disk space (10 disk spaces) were reviewed on a single computer monitor with 1.5x magnification. The site and circumferential location (ie, side) of the primary IVD extrusion as well as the location of any additional extradural compressions were determined by use of T2W images. Signal intensity of disk spaces, extradural compressions, and the spinal cord were assessed on the MR images at the 10 disk spaces, and findings were recorded by use of a customized scoring system (designed by the authors) that allowed conversion to a numeric system for statistical analysis. Accuracy for a given modality was defined as the percentage of dogs for which either a consensus or 2 of the 3 reviewers recorded findings identical to those determined surgically for the evaluated variables. Inter-reviewer agreement was recorded to compare answers between reviewers and was not dependent on the surgical results.

All myelographic projections were reviewed on a back lit radiographic viewer. Lateral and ventrodorsal myelographic projections from the T9-10 to the L5-6 disk space were reviewed (10 disk spaces in total). For purposes of this evaluation, oblique projections were not examined. The site and side of suspected extradural compressions were recorded by each reviewer. The subarachnoid space was assessed for evidence of attenuation, obstruction of contrast flow, or deviation of the contrast column. Disk spaces were assessed for mineralization. Accuracy and inter-reviewer agreement were recorded as described for MRI evaluations.

Statistical analysis—Intermethod and inter-reviewer agreement were determined by calculating κ scores for multiple categories and multiple reviewers. The quality of agreement was measured according to the method described by Landis and Koch:30 κ values < 0 to < 0.2 were interpreted as slight agreement, values of 0.2 to < 0.4 as fair agreement, values of 0.4 to < 0.6 as moderate agreement, values of 0.6 to < 0.8 as substantial agreement, and values ≥ 0.8 as near-perfect agreement. A 95% CI was calculated for each estimate of agreement. Accuracy for a given modality was defined as the percentage of dogs for which either a consensus or 2 of the 3 reviewers recorded findings identical to those determined surgically for the evaluated variables.

Results

Twenty-four dogs met the inclusion criteria for the study. Breeds included Dachshund (n = 8), Shih Tzu (4), Cocker Spaniel (2), Bichon Frisé (1), Maltese (2), Beagle (2), Miniature Poodle (1), and Jack Russell Terrier (1); 3 dogs were crossedbreed. Fourteen dogs were male, and 10 were female; median age was 5.9 years (range, 2 to 10 years).

Neurologic signs in the 24 dogs were scored at the time of admission as grade 1 (signs of back pain with no neurologic deficits) in 2 (8.3%), as grade 2 (ambulatory paraparesis) in 12 (50%), as grade 3 (nonambulatory paraparesis) in 3 (12.5%), and as grade 4 (paraplegia with positive deep pain perception) in 7 (29.2%). No dogs had grade 5 neurologic signs (paraplegia, inability to micturate, and loss of deep pain perception). The median and mean duration of neurologic signs were 3.5 and 15.1 days, respectively, with a range of 1 to 150 days. Twelve of the 22 dogs that had surgery had neurologic signs for < 5 days.

Diagnostic imaging and surgical procedures—Twenty-two dogs underwent MRI, which was followed immediately by myelography. The order of imaging was reversed for 1 dog because of a conflict with the MRI schedule. The MRI of the remaining dog was performed 2 days after myelography because the dog was hypothermic and hypotensive after prolonged general anesthesia for a complicated myelogram. The dog was ambulatory prior to MRI and did not deteriorate neurologically between imaging procedures. Twenty-one patients underwent unilateral minihemilaminectomy at the suspected site, and 1 underwent bilateral minihemilaminectomy at 1 site immediately after diagnostic imaging. Two dogs did not undergo surgical intervention because surgery was not deemed to be warranted by the attending radiologist and surgeon. Data from these 2 dogs were eliminated from all analysis related to surgical findings.

Review of MR images—All 3 reviewers identified the same site of IVD extrusion on T1W images in 16 of 24 (66.7%) dogs, and 2 of 3 identified the same site in 7 dogs. Overall, the same site was identified by ≥ 2 of 3 reviewers for 23 of 24 (95.8%) dogs. In the remaining dog, 2 of 3 reviewers identified 1 site but failed to identify a contralateral, adjacent lesion (although all 3 reviewers detected both extrusions on T2W images). Inter-reviewer agreement for site by use of T1W images was calculated for each estimate of agreement. Accuracy of T1W MRI for determining site, compared with surgical findings (with agreement between ≥ 2/3 reviewers), was 90.9% (20/22 dogs).

All 3 reviewers identified the same site of IVD extrusion on T2W images in 17 of 24 (70.8%) dogs, and 2
of 3 reviewers identified the same site in 6 dogs. Overall, ≥ 2 of 3 reviewers identified the same site in 23 of 24 (95.8%) dogs. Inter-reviewer agreement for site by use of T2W images was substantial (κ = 0.70; 95% CI, 0.59 to 0.80). The accuracy of T2W MRI for determining side, compared with surgical findings (with agreement between ≥ 2/3 reviewers), was 95.5% (21/22 dogs).

The same side of IVD extrusion relative to the spinal cord was identified on T2W images by all 3 reviewers in 15 of 24 (62.5%) dogs and by 2 of 3 reviewers in 8 dogs. Overall, ≥ 2 of 3 reviewers identified the same side in 23 of 24 (95.8%) dogs. Inter-reviewer agreement for side of extrusion by use of the T2W images was substantial (κ = 0.61; 95% CI, 0.48 to 0.80). For 1 dog, none of the reviewers were in agreement with regard to the side of the lesion.

The accuracy of T2W MRI for identifying the side of IVD extrusion, compared with surgical findings (with agreement between ≥ 2/3 reviewers), was 86.4% (19/22 dogs). In 3 dogs, T2W transverse images suggested that the extrusion was ventral to the spinal cord, and this was confirmed in the surgical reports. Left-sided extrusions in 7 of 21 dogs and right-sided extrusions in 10 dogs were confirmed surgically after identification in T2W images; 1 dog had 2 adjacent and contralateral extrusions, and these were considered once in each of the left and right counts.

T2-weighted sagittal and transverse images were used to assess IVD integrity. All 240 disks evaluated in the present study had identifiable signal changes consistent with degeneration (eg, signal intensity of the nucleus pulposus ranged from hypointense relative to CSF to void of signal, compared with normal nucleus pulposus material, which is hyperintense relative to CSF).

Sagittal and transverse Gd-DTPA–enhanced T1W images were obtained in 15 dogs. All reviewers selected the same site in 14 of 15 (93.3%) dogs, and 2 of 3 reviewers selected the same site in 1. The site of IVD extrusion determined by use of contrast-enhanced T1W images was confirmed by surgical findings in all 15 dogs. The accuracy of Gd-DTPA–enhanced T1W images for determining site, compared with surgical findings (with agreement between ≥ 2/3 reviewers), was 100% (15/15 dogs). Peripheral enhancement of the extruded nuclear material was recorded by ≥ 2 of 3 reviewers in 6 of 15 (40%) dogs (Figure 1). These 6 dogs had neurologic signs for durations ranging from 12 hours to 7 days; 4 of the 6 dogs had grade 4 neurologic signs prior to surgery, and neurologic signs of grade 1 and grade 2 were assessed in the other 2 dogs, with a moderate amount of firm disk material collected at surgery.

Accuracy of the combination of T1W images, T2W images and Gd-DTPA–enhanced images for determining site and side of IVD extrusion was 100% (15/15) for dogs that underwent minihemilaminectomy. All 3 reviewers agreed on the site of extrusion when all 3 sequences were used in combination. A focal region of intraparenchymal spinal cord hyperintensity was detected on T2W images in 4 dogs by 2 of 3 reviewers. Before surgery, neurologic signs were grade 4 in 2 of these dogs and grade 2 in the remaining 2 dogs. All reviewers subjectively described visualization of signal changes in the spinal cord on transverse images in these dogs as challenging.

Transverse GRE images were obtained in 20 dogs and revealed an extradural susceptibility artifact at the site of extrusion in 5. Four of these 5 dogs reportedly had rapid neurologic deterioration over 2 or 3 days and grade 4 neurologic signs at evaluation, whereas 1 dog had a 9-day history of neurologic signs assessed as grade 2 at evaluation.

Review of myelographic images—All 24 dogs underwent myelography at L5-6, and 1 underwent additional intrathecal contrast medium injections at L6-7.

Figure 1—Representative transverse Gd-DPTA–enhanced T1W MR (A) and right lateral myelographic (B) images of a dog with thoracolumbar IVD extrusion. A—The Gd-DPTA–enhanced T1W MR image was obtained at the site of IVD extrusion (L5-6). The extruded disk material has a peripheral ring of enhancement at the level of the disk space on the left side (arrow). B—The myelographic image reveals obstruction of contrast medium flow at the level of T11-12 (thick arrow) and an epidural accumulation of contrast material at L5-6 (thin arrow). Iohexol was initially injected into the subarachnoid space at L5-6, and contrast agent administration was repeated at the cerebellomedullary cistern. Results of myelographic examination were nondiagnostic, and the MRI findings were used to guide the surgical approach, which confirmed the left-sided L5-6 IVD extrusion. R = Right side.
and the cerebellomedullary cistern. In this dog, alternate injection sites were chosen because contrast material was not detectable caudal to T11-L2 and neurologic examination findings were consistent with a caudal lumbar lesion. The myelographic results for this dog were considered to be nondiagnostic by all 3 reviewers, with the myelographic results for the other 23 dogs considered diagnostic.

All 3 reviewers identified the same site of IVD extrusion by use of the lateral and ventrodorsal myelographic projections in 17 of 24 (70.8%) dogs, and 2 of 3 reviewers identified the same site in 5 of the remaining 7 dogs. Overall, ≥ 2 of 3 reviewers recorded the same site in 22 of 24 (91.7%) dogs. Inter-reviewer agreement for site of extrusion was substantial (κ = 0.72; 95% CI, 0.60 to 0.79). In the dog with adjacent contralateral disk extrusions, all 3 reviewers identified both lesions on the ventrodorsal myelographic projection. The accuracy of 2-view myelography for determining site, compared with surgical findings (with agreement between ≥ 2/3 reviewers), was 90.9% (20/22 dogs). Agreement between myelographic and surgical findings for site of extrusion was near perfect (κ = 0.88; 95% CI, 0.73 to 1.0).

Inter-reviewer agreement for identification of the side of IVD extrusion relative to the spinal cord on myelographic projections was fair (κ = 0.37; 95% CI, 0.23 to 0.49). In 9 of 24 (37.5%) dogs, all 3 reviewers identified the same side, and in 7 dogs, 2 of 3 reviewers identified the same side. Overall, ≥ 2 of 3 reviewers identified the same side in 16 of 24 (66.7%) dogs. None of the reviewers could determine the side of extrusion in 1 dog. Accuracy of the ventrodorsal myelographic projection for determining side of IVD extrusion, compared with surgical findings (with agreement between ≥ 2/3 reviewers), was 54.3% (12/22 dogs).

Comparison of MRI and myelography—There was substantial agreement (κ = 0.71; 95% CI, 0.52 to 0.84) between MRI and myelography for the identification of site of IVD extrusion. Agreement between results for the 2 modalities combined and surgical findings was also substantial (κ = 0.78; 95% CI, 0.67 to 0.84) for this variable.

Intermethod agreement for side of IVD extrusion was moderate (κ = 0.40; 95% CI, 0.18 to 0.62), and agreement for side between the 2 imaging modalities and surgical findings was also moderate (κ = 0.43; 95% CI, 0.32 to 0.59). The same side was identified by all 3 reviewers by use of myelography and MRI, with these findings subsequently confirmed by surgical records, in only 8 of 22 (36.4%) dogs. In 6 of the remaining 14 dogs, the side identified by use of MRI by all 3 reviewers matched that identified surgically, whereas all 3 reviewers suggested different circumferential locations of extrusion on evaluation of the corresponding myelographic projections. One reviewer was unable to determine the side of extrusion in 1 dog by use of MR images, and the other 2 reviewers suggested locations right and ventral to the spinal cord during review of the images for the other 2 dogs.

Because results of a previous study indicated that ventrodorsal myelography alone is accurate for site of injury on lateral and ventrodorsal projections. The surgical reports for 2 of these dogs confirmed the presence of hemorrhage at the site of extrusion.

Although reviewers detected degeneration in 100% of the 240 disks evaluated on sagittal T2W images, evaluation of lateral survey radiographs and myelographic projections revealed that only 65 (27.1%) were mineralized (Figure 2). Thirty-four of the 65 (52.3%) mineralized disks were detected in Dachshunds. None of the mineralized sites corresponded to a site of extrusion.

Discussion

In the study reported here, accuracy of T2W MRI for the determination of site and side of thoracolumbar IVD extrusion in small-breed dogs was 95.5% and 86.4%, respectively, compared with 90.9% and 54.5%, respectively, for myelography. This was likely attributable to the fact that although myelography provides excellent contrast resolution, the 2-D projections result in superimposition of the osseous and soft tissue structures within the vertebral canal, which can make interpretation difficult.21 Recent studies12,22,23 in dogs and humans evaluating the use of myelography as an independent imaging modality have included oblique projections in their protocols in addition to the standard lateral and ventrodorsal projections, with accurate identification of the side of IVD extrusion in up to 95% of cases. Oblique projections were not included in the present study because results of a previous study1 indicated that ventrodorsal myelography alone is accurate.
for determining the side of the lesion in up to 89% of cases; also, these projections were not standard practice at the hospital where the study was performed between 2004 and 2007 and were only available for a few of the dogs of the present study. In retrospect, inclusion of oblique projections in our protocol may have improved inter-reviewer agreement for circumferential lesion localization.

In contrast to myelography, MRI provides images that allow differentiation between soft tissue and bony structures of the spine in the sagittal, dorsal, and transverse planes, thereby offering greater spatial resolution.21 For these reasons, MRI is now considered the imaging method of choice in human patients with lumbar IVD herniation.24 Many reports3-6,12,25 describing the appearance of thoracolumbar IVD extrusions on images obtained by use of myelography and MRI have been published in the human and veterinary literature. In 1 study,26 investigators compared the use of multplanar CT and myelography in dogs with IVD extrusion. In another study,27 CT and MRI findings were compared with surgical findings in 35 dogs with degenerative lumbosacral stenosis. Investigators of that study27 concluded that although there was substantial agreement between CT and MRI findings for determining the site of disk protrusion, agreement between each modality and surgical findings was only moderate. In the present study, we determined that intermethod agreement was substantial between MRI and myelography, whereas the agreement between the individual modalities and surgical findings was near perfect. The apparently stronger agreement between MRI and surgical findings in the present study may have been the result of similar positioning of dogs during imaging and surgery; in the previous study,27 the difference in position during these procedures was identified as a possible reason for poor agreement. When reviewers were unable to identify the lesion site in images obtained with one of these modalities, diagnostic localization was made by use of the other. This may have been attributable to the small sample number and the small size of the dogs that were evaluated. It may also suggest that MRI and myelography have distinct uses and that the use of both methods may be necessary to confirm the surgical site in some situations.

Inter-reviewer agreement was similar for individual MRI sequences and 2-view myelography but was improved when results for multiple MRI sequences were combined. Accuracy for identification of IVD extrusion site in Gd-DTPA enhanced T1W images was 100% in 15 dogs, whereas accuracy was 90.9% for T1W images without contrast medium in the 22 dogs that underwent minihemilaminectomy. All 3 reviewers identified the same IVD extrusion site in 16 of 24 (66.7%), 17 of 24 (70.8%), and 14 of 15 (93.3%) dogs by use of T1W, T2W, and Gd-DTPA-enhanced T1W images, respectively. All 3 reviewers identified the same site in 15 of 15 dogs for which all sequences were available. However, all 3 reviewers agreed on site in myelographic images for only 70.8% of dogs. This variability among reviewers may have been related to differences in experience with the imaging modalities. Two of the 3 reviewers (the surgeon and the surgery resident) had limited experience with MRI prior to this study and more experience with myelographic interpretation. The use of contrast-enhanced MRI may have aided the diagnostic localization by reviewers who were more comfortable evaluating myelographic images. This suggests the combination of multiple MRI sequences, including T1W, T2W, and contrast-enhanced T1W images, may improve a viewer’s ability to accurately detect the location of an IVD extrusion.

Although agreement for IVD extrusion site between MRI and myelography was substantial, agreement for determination of the side of extrusion was only moderate. The accuracies of T2W MRI, multisequence MRI, and myelography for determining the side of extrusion were 86.4%, 100% and 54.5%, respectively, as determined on the basis of results of surgical findings. Accuracy of the ventrodorsal myelographic images for determination of the side of extrusion in the present study (54.5%) was much lower than the 89% accuracy previously reported by our group.7 Reasons for this are unclear. Influencing factors may include differences in sample size and duration of clinical signs between patients in the previous study7 and the present study. In the present study, only 22 dogs underwent surgery and only 12 of 22 (54.5%) had neurologic signs at evaluation that had been present for <5 days. In contrast, 80 of 104 (76.9%) dogs in the previous study7 had neurologic signs for <5 days prior to evaluation.

Surgical findings were considered the gold standard for site and side of IVD extrusion in the present study, and localization of lesions was confirmed in 22 of 24 dogs during removal of extruded disk material at surgery. In 2 dogs without evidence of extradural compression on MRI, the absence of extruded material was not confirmed because surgical exploration was deemed unnecessary. The use of surgery as a gold standard for the localization of IVD extrusions has been criticized26,27,28,29,30. The surgical site is small, there may be intraoperative hemorrhage, and the extrusion may extend cranially or caudally beyond the bony window created or toward the contralateral side. Although comparison to surgical findings may be less than ideal, several recent studies9,22,26,27 have also used surgery as the gold standard for site identification. Alternatives for definitive localization of IVD extrusion are surgical exploration of the entire thoracolumbar spine and postmortem examination; these are not options for clinical patients.12,23,26,29,30 Results of the present study suggest that surgery and the combination of multiple MRI sequences could each potentially be considered gold standards for future studies involving naturally occurring IVD extrusion in small-breed dogs.

Yamada et al17 compared the use of myelography with sagittal T1W and T2W MRI scans to limit MRI times in 3 clinically affected small-breed dogs with IVD extrusion. Results of that study17 suggested that transverse MR images in Dachshunds and Beagles had a low signal-to-noise ratio in a small field of view and did not accurately reflect the integrity of the spinal cord parenchyma. Magnetic resonance imaging in the present study was performed with a 1.5-T scanner, and all dogs weighed <20 kg. Our results indicated that the use of transverse images was essential to determine the side of
the IVD extrusion and pattern of gadolinium enhancement within the extruded material and spinal cord. However, T2W and Gd-DTPA enhanced transverse images did not consistently reveal good spinal cord parenchymal definition, and changes in spinal cord intensity may have been overlooked. Increases in spinal cord signal intensity on T2W images have been associated with edema, hemorrhage, and myelomalacia in human and veterinary patients. We were unable to consistently determine sites of signal hyperintensity, possibly because of the large number of dogs with low-grade neurologic dysfunction, small size of the dogs resulting in low MRI resolution, or relative inexperience of the 2 surgeons at interpreting MR images at the time the present study was performed. Three-millimeter slice thickness was obtained in transverse imaging, and it is possible that decreasing the slice thickness and field of view could have increased the contrast resolution to permit visualization of small details.

In 1 dog, the site of IVD extrusion was identified via myelography, whereas results of MRI were inconclusive. The myelographic findings were identical for the site identified via myelography, whereas results of MRI were inconclusive. The myelographic findings were identical for the site identified via myelography, whereas results of MRI were inconclusive. The myelographic findings were identical for the site identified via myelography, whereas results of MRI were inconclusive. The myelographic findings were identical for the site identified via myelography, whereas results of MRI were inconclusive. The myelographic findings were identical for the site identified via myelography, whereas results of MRI were inconclusive.

Peripheral ring enhancement of herniated disk material on MRI studies has been shown to correlate with vascularized granulation tissue surrounding avascular sequestered disk material in humans. Six of 15 dogs that received Gd-DTPA IV in the present study had peripheral enhancement of the extradural compressive lesion. Data from the medical history of these patients indicated neurologic signs of a duration of 12 hours to 7 days. Dogs can tolerate a moderate amount of spinal cord compression without evidence of neurologic deficits. Therefore, we could not rule out a slowly progressive, chronic disk extrusion that resulted in the formation of granulation tissue with a more acute neurologic deterioration caused by further extrusion in these dogs. Peripheral enhancement could also be related to venous sinus disruption at the time of extrusion.

All 240 IVDs assessed in the present study had evidence of degeneration on MR images, whereas only 65 (27.1%) had mineralization detected on radiographic projections. A healthy nucleus pulposus of neonates is composed of approximately 80% water; however, as it degenerates, the water content decreases and the collagen content increases. The degeneration can occur as early as 3 to 4 months of age in chondrodystrophic-breed dogs such as Dachshunds and Beagles. The other breeds represented in the present study have also been reported to undergo disk degeneration and develop IVD extrusion, although histologic evaluation studies have not been performed to confirm them as chondrodystrophic. Spin-echo MRI sequences are able to detect reduction in nuclear water content because the number of mobile protons decreases, and the relaxation rates of the various tissues are altered. Radiographs are not sensitive enough to detect the change in water content but can detect mineralization of the nucleus pulposus, which indicates an advanced stage of disk degeneration. An interesting and previously unreported finding of the present study was that none of the extruded disks had evidence of radiographic mineralization at the time of imaging. It has previously been reported that IVD mineralization at 2 years of age is a significant predictor of clinical disk extrusion in Dachshunds and that mineralization of ≥ 5 disks at the time of surgery correlates with an increased risk of recurrence in both chondrodystrophic and nonchondrodystrophic dogs. Thirty-four of 65 (52.3%) mineralized disks in the present study were found in Dachshunds. Disappearance of disk mineralization has been reported in Dachshunds, especially in dogs > 2 years of age that have > 4 mineralized disks. Ages of dogs in the present study ranged from 2 to 10 years, and it was impossible to determine whether the extruded disks had been mineralized in appearance at an earlier time. To the authors’ knowledge, a study comparing the MRI and radiographic appearance of canine disk spaces over time has not been performed.

A disadvantage of MRI for routine evaluation of dogs with IVD extrusion is the possible lack of avail-
ability of a scanner, especially for emergency evaluation. During the present study, it was common at the Ontario Veterinary College Teaching Hospital to perform myelo-
graphic evaluation of the lumbar spine on an emergency basis in animals with suspected IVD extrusion and se-
vere or rapidly progressive neurologic signs that were
deemed to require immediate surgery. This limited the
enrollment of dogs with grade 4 or 5 neurologic signs in
the study because many of these were treated on an emergency basis and could therefore not undergo MRI,
which was not available on a 24-hour basis.

In the study reported here, multisequence MRI provided more consistent and accurate results than did 2-view orthogonal myelography in small-breed dogs with first-time thoracolumbar IVD extrusion. On the basis of these results, we believe that myelography may be most advantageous for emergency diagnosis, when MRI is unavailable, or when MRI reveals multiple sites of IVD extrusion to determine the site of the extrusion causing clinical signs. We recommend transverse and sagittal T1W, T2W, and contrast-enhanced T1W MRI sequences with transverse GRE images for assessment of naturally occurring thoracolumbar IVD extrusion in small-breed dogs.

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From this month’s *AJVR*

**Changes in heart rate and heart rate variability during transportation of horses by road and air**

Hajime Ohmura et al

**Objective**—To determine the influence of transportation by road and air on heart rate (HR) and HR variability (HRV) in horses.

**Animals**—6 healthy horses.

**Procedures**—ECG recordings were obtained from horses before (quarantine with stall rest [Q]; 24 hours) and during a journey that included transportation by road (RT; 4.5 hours), waiting on the ground in an air stall (W; 5.5 hours), and transportation by air (AT; 11 hours); HR was determined, and HRV indices of autonomic nervous activity (low-frequency [LF; 0.01 to 0.07 Hz] and high-frequency [HF; 0.07 to 0.6 Hz] power) were calculated.

**Results**—Mean ± SD HRs during Q, RT, W, and AT were 38.9 ± 1.5 beats/min, 41.7 ± 5.6 beats/min, 41.5 ± 4.3 beats/min, and 48.8 ± 5.6 beats/min, respectively; HR during AT was significantly higher than HR during Q. The LF power was significantly higher during Q (3,454 ± 1,087 milliseconds²) and AT (3,101 ± 567 milliseconds²) than it was during RT (1,824 ± 432 milliseconds²) and W (2,072 ± 616 milliseconds²). During Q, RT, W, and AT, neither HF powers (range, 509 to 927 milliseconds²) nor LF:HF ratios (range, 4.1 to 6.2) differed significantly. The HR during RT was highly correlated with LF power (R² = 0.979), and HR during AT was moderately correlated with the LF:HF ratio (R² = 0.477).

**Conclusions and Clinical Relevance**—In horses, HR and HRV indices during RT and AT differed, suggesting that exposure to different stressors results in different autonomic nervous influences on HR. (*Am J Vet Res* 2012;73:515–521)