COMPARISON OF NONCONTRAST COMPUTED TOMOGRAPHY AND HIGH-FIELD MAGNETIC RESONANCE IMAGING IN THE EVALUATION OF GREAT DANES WITH CERVICAL SPONDYLOMYELOPATHY

PAULA MARTIN-VAQUERO, RONALDO C. DA COSTA, WM TOD DROST

Computed tomography (CT) provides excellent bony detail, whereas magnetic resonance (MR) imaging is superior in evaluating the neural structures. The purpose of this prospective study was to assess interobserver and intermethod agreement in the evaluation of cervical vertebral column morphology and lesion severity in Great Danes with cervical spondylomyelopathy by use of noncontrast CT and high-field MR imaging. Fifteen client-owned affected Great Danes were enrolled. All dogs underwent noncontrast CT under sedation and MR imaging under general anesthesia of the cervical vertebral column. Three observers independently evaluated the images to determine the main site of spinal cord compression, direction and cause of the compression, articular process joint characteristics, and presence of foraminal stenosis. Overall intermethod agreement, intermethod agreement for each observer, overall interobserver agreement, and interobserver agreement between pairs of observers were calculated by use of kappa (κ) statistics. The highest overall intermethod agreements were obtained for the main site of compression and direction of compression with substantial agreements ($\kappa = 0.65$ and 0.62, respectively), whereas the lowest was obtained for right-sided foraminal stenosis ($\kappa = 0.39$, fair agreement). For both imaging techniques, the highest and lowest interobserver agreements were recorded for the main site of compression and degree of articular joint proliferation, respectively. While different observers frequently agree on the main site of compression using both imaging techniques, there is considerable variation between modalities and among observers when assessing articular process characteristics and foraminal stenosis. Caution should be exerted when comparing image interpretations from multiple observers. © 2014 *American College of Veterinary Radiology.*

Key words: cervical spine, CT, dog, MRI, wobbler syndrome.

Introduction

CERVICAL SPONDYLOMYELOPATHY has been recognized as a common cause of neurological signs in Great Danes since the 1960s.[1,2] Great Danes typically suffer from osseous-associated cervical spondylomyelopathy with spinal cord/nerve root compression and foraminal stenosis secondary to absolute cervical vertebral canal stenosis caused by abnormal proliferation of the vertebral arch, articular processes, and/or pedicles.[1,3,4] Vertebral malformations, ligamentous hypertrophy, and extradural synovial cysts can also be present.[1,3] Magnetic resonance (MR) imaging is currently considered the imaging modality of choice in the diagnosis of canine cervical spondylomyelopathy.[4–6] However, only a few studies have objectively compared the relative advantages or disadvantages of the various imaging modalities in the diagnosis of canine cervical spondylomyelopathy, focusing on the disc-associated form of this disease.[6,7] In disc-associated cervical spondylomyelopathy, cervical spinal cord compression is typically caused by intervertebral disc protrusion.[8] In osseous-associated cervical spondylomyelopathy, the main cause of compression originates from bony structures.[1,4] Since the pathologic changes underlying both forms of canine cervical spondylomyelopathy are different, results from studies investigating disc-associated cervical spondylomyelopathy cannot be extrapolated to the osseous-form of the disease.

From the Department of Veterinary Clinical Sciences, College of Veterinary Medicine, Ohio State University , Columbus, OH, 43210.

This work was performed at the College of Veterinary Medicine, Ohio State University, Columbus, OH 43210, USA.

Funding sources: This work was supported by the Great Dane Club of America, an Intramural Canine grant from The Ohio State University, College of Veterinary Medicine, and the Award Number Grant UL1TR000090 for The Ohio State University Center for Clinical and Translational Science (CCTS) from the National Center for Advancing Translational Sciences. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Center for Advancing Translational Sciences or the National Institutes of Health.

Previous presentations: Presented in part as a Research Abstract in the Annual Forum of the American College of Veterinary Internal Medicine (ACVIM) in Seattle, Washington in June 2013.

Address correspondence and reprint requests to Paula Martin-Vaquero, at the above address. E-mail: paulagu83@gmail.com

Received November 2, 2013; accepted for publication December 8, 2013.

doi: 10.1111/vru.12148

Canine cervical spondylomyelopathy bears similarities with the human disease known as cervical spondylotic myelopathy, which is a chronic compressive myelopathy.[3,9,10] Magnetic resonance imaging has become the preferred screening method for evaluation of cervical myelopathy and radiculopathy in people.[10–12] However, there is still controversy as to what imaging modality is the gold standard to diagnose this disease in people.[11–15] Several studies have compared the noncontrast computed tomography (CT), CT-myelography, and MR imaging findings in humans with cervical compressive myelopathy.[11–14,16–19] In human neurology, discrepancies frequently arise in the interpretation of advanced imaging studies in patients with cervical degenerative disease, especially in differentiating discogenic and osseous pathology and in establishing the severity of disease.[11] Both CT and MR imaging have advantages and disadvantages. It is generally accepted that CT provides excellent bony detail, whereas MR imaging is superior in evaluating soft tissue structures.[11,20] When compared to MR imaging, CT advantages include lower cost, faster acquisition of images, and fewer artifacts from metal.[20] An additional benefit of noncontrast CT applicable to veterinary medicine is the possibility of acquiring CT studies under sedation.[21] The main advantages of MR imaging include the ability to obtain images in any anatomic plane, as well as excellent soft tissue contrast resolution and the ability to detect intraparenchymal disease and signal changes within the spinal cord.[10,12,20]

A recent study compared the diagnostic sensitivity and observer agreement of noncontrast CT and MR imaging in the evaluation of thoracolumbar intervertebral disc herniation in dogs.[22] To date, there is no equivalent study in the veterinary literature obtained from dogs with osseous-associated cervical spondylomyelopathy. Considering that the vast majority of Great Danes have a form of cervical spondylomyelopathy primarily associated with osseous pathology,[3,4] it is possible that CT may yield similar information when compared to MR imaging in regards to vertebral canal and foraminal stenosis. This fact, together with the possibility of acquiring noncontrast CT studies under sedation, would potentially make this imaging modality an attractive option for short- and long-term follow-up of dogs with osseous-associated cervical spondylomyelopathy. The purpose of this prospective study was to assess interobserver and intermethod agreement in the evaluation of cervical vertebral column morphology and lesion severity in Great Danes with cervical spondylomyelopathy by use of noncontrast CT and high-field MR imaging. We hypothesized that both imaging modalities would be useful in identifying the main site of spinal cord compression, but MR imaging would be superior at identifying the presence of foraminal stenosis, whereas CT would be superior for depicting articular process joint abnormalities.

Methods

Fifteen client-owned Great Danes were prospectively enrolled between April 2011 and October 2012. The investigation was conducted in accordance with the guidelines and with approval of the Clinical Research Advisory Committee and the Institutional Animal Care and Use Committee. Written owner consent was obtained prior to study enrollment. Great Danes were eligible for enrollment if they had clinical signs and neurologic exam findings consistent with cervical spondylomyelopathy and diagnostic confirmation using CT and MR imaging. The time of onset of clinical signs and neurologic exam findings at the time of enrollment were recorded. All dogs underwent complete physical and neurologic examinations performed by two of the investigators (P.M.V. and R.dC.), complete blood counts, serum biochemical profiles, and CT and MR imaging of the cervical vertebral column. Computed tomography and MR imaging studies were obtained within a 48-h period. Whether CT or MR imaging was performed first or second depended on the day of the week the dog presented to our facility, which determined MR imaging availability. Seven intervertebral spaces from C2–3 through T1–2 were imaged with both modalities in all dogs.

All CT examinations were done with dogs under sedation using an 8-slice CT scanner (GE LightSpeed Ultra 8-slice, GE Healthcare, Waukesha, WI). Each dog was sedated with hydromorphone (0.05–0.1 mg/kg IV, West-Ward Pharmaceuticals, Eatontown, NJ) and dexmedetomidine (4–8 mcg/kg IV, Dexdomitor®, Pfizer Animal Health, New York, NY). Dogs were positioned in sternal recumbency with the head and neck extended in neutral position. Scanning parameters included: 120 kV, automatic mA (min = 100 mA), axial mode, 2.5 mm contiguous transverse slices using standard and bone algorithms. The transverse slices were aligned parallel to the intervertebral spaces.

MR imaging of the cervical vertebral column was obtained with all dogs under general anesthesia with a 3.0 Tesla magnet (Achieva 3.0 Tesla, Philips Healthcare, Best, The Netherlands) and a surface coil. Dogs were positioned in dorsal recumbency with the head and neck extended in neutral position. Images were acquired using a turbo spin-echo technique. Transverse T1-weighted and T2-weighted images were obtained. Repetition time (TR) and echo time (TE) were as follows: T1-weighted, TR = 650 ms, TE = 8 ms; T2-weighted, TR = 4000 ms, TE = 120 ms. The number of acquisitions was 2. The flip angle was set at 90°. The field of view was 20 cm with matrix dimensions of 200 × 192 mm. Slice thickness was set at 3 mm with no interslice interval. Five transverse slices were obtained at each intervertebral disc space from C2–3 through T1–2. The transverse slices were aligned parallel to the intervertebral disc and arranged to pass through the center of each

intervertebral space as well as the cranial and caudal end plates of the adjacent vertebral bodies.

Three observers independently evaluated the CT and MR imaging studies (observer 1, (P.M.V.), veterinary neurology resident; observer 2 (W.T.D.), board-certified veterinary radiologist; and observer 3 (R.dC.), board-certified veterinary neurologist). The observers were aware of the patient information; however, it was determined that all observers would evaluate and grade the CT studies from all 15 dogs first, and then, review all 15 MR imaging studies. Images were reviewed using dedicated software (E-Film Merge Healthcare, Milwaukee, WI). The morphologic features evaluated included the following: main site and additional site(s) of spinal cord compression, direction and cause of the compression, articular process joint characteristics, and presence of foraminal stenosis. Prior to image evaluation, observers were provided with a sample set of CT and MR images depicting the different grades available for those morphologic features that were graded (articular process joint characteristics and foraminal stenosis).

All available transverse images through an intervertebral space were used to identify the main site as well as any additional site(s) of compression. The direction of the compression was recorded as dorsal, ventral, or lateral. Dorsolateral and ventrolateral compressions were included in the lateral group. If more than 1 direction of compression was present, all types were recorded but the direction of the most severe compression was used for statistical analysis. The cause of compression was classified as intervertebral disc-associated, osseous-associated (articular process joint, pedicle, and/or lamina proliferative changes), or due to soft tissue hypertrophy (ligamentous hypertrophy). For these morphologic features, observers could adjust the window width and level at will when evaluating CT images. When assessing MR images, observers could use both T1-weighted and T2-weighted images. Observers were not instructed to record the spinal cord signal changes visualized on MR images but, if present, observers could use those signal changes at their discretion as additional information to guide their decision when selecting the main site of compression.

The characteristics of the articular process joints were evaluated on CT images using a bone window, and on MR imaging studies using both T1-weighted and T2-weighted images. In order to assess the articular process joint characteristics, observers used the transverse image centered at the middle of each intervertebral space plus the two adjacent images (one cranial and one caudal). The observers evaluated and graded the following two features: (i) the regularity of the articular surface and presence of subchondral bone sclerosis, and (ii) the degree of articular process joint proliferation. The regularity of the articular surface and presence of subchondral bone sclerosis was graded as follows: zero, if the articular surface was smooth with no evidence of subchondral bone sclerosis; one, if it was smooth but with evidence of sclerosis; and two, if it was irregular and sclerotic. The degree of articular process joint proliferation was graded as zero, if the articular process joint was considered to have a normal size, one, if there was mild proliferation consistent with an articular process joint <25% larger than the expected normal size, two, if there was moderate proliferation with an articular process joint 25–50% larger than normal, and three, if there was severe proliferation with an articular process joint >50% larger than the expected normal size.[4,23,24] Right and left sides were evaluated and graded separately.

The presence of foraminal stenosis was assessed on CT images using both soft tissue and bone windows and evaluating the transverse image obtained at the center of the intervertebral space for every space imaged. Transverse T1-weighted and T2-weighted images obtained at the center of the intervertebral space were used to assess the presence of foraminal stenosis on MR images. Right and left sides were also evaluated and graded separately. The presence of foraminal stenosis was subjectively classified as absent, mild (<25% stenosis), moderate (25–50% stenosis), or severe (>50% stenosis).[25,26]

All statistical analysis were selected and performed by a professional biostatistician using commercially available software (Stata, version 12.1, Stata Corporation, College Station, TX). Statistical analysis was performed using the kappa (κ) test to compare the intermethod agreement (noncontrast CT compared to MR imaging) for every morphologic feature evaluated based on all interpretations of all observers (overall intermethod agreement) as well as for each one of the three observers individually. A modified Fleiss κ was used to calculate the overall interobserver agreement for CT and MR imaging (agreement among the three observers for each individual imaging modality) for every feature evaluated.[27] In order to use this type of κ, the number of observers per feature assessed needs to be constant.[27] The interobserver agreement between pairs of observers (observers 1 and 2, 1 and 3, and 2 and 3) was also calculated. The strength of agreement was interpreted as follows: almost perfect agreement ($\kappa = 0.81$–1.00), substantial ($\kappa = 0.61$–0.80), moderate ($\kappa = 0.41$–0.60), fair ($\kappa = 0.21$–0.40), slight ($\kappa = 0.00$–0.20), and poor ($\kappa < 0.00$).[28]

Results

Two spayed females, 12 neutered males, and one intact male were enrolled. Their mean age at the time of study enrollment was 3.9 years (range, 1–7.2 years). The mean weight was 57.8 Kg (range, 42–79.3 Kg). The reported mean age at the onset of signs was 1.9 years (range, 0.4–4.2 years). The clinical signs had been present for a mean

time of 1.9 years (range, 0–5 years) before enrollment in the study. Fourteen of the 15 Great Danes showed ambulatory tetraparesis with proprioceptive ataxia of all four limbs. One dog showed a hypertonic thoracic limb gait with ambulatory paraparesis and proprioceptive ataxia of the pelvic limbs. All dogs had delayed postural reactions involving all four limbs. Mild neck pain was elicited in six dogs at the time of examination. For both imaging modalities and all three observers, the main site of spinal cord compression was most commonly reported at C6–7. Similarly, osseous-associated compressions in the lateral direction were most commonly recorded.

The κ values for the overall agreement between the two imaging modalities (overall intermethod agreement) as well as the intermethod agreement for each individual observer were calculated (Table 1). The highest overall intermethod agreement was obtained for the main site of compression with a substantial $\kappa = 0.65$. The overall intermethod agreement was also substantial for the direction of compression with $\kappa = 0.62$. The overall intermethod agreement was fair to moderate for the cause of the compression, regularity of the articular surfaces, degree of articular process joint proliferation, and foraminal stenosis. The lowest overall intermethod agreement was obtained for the left-sided degree of articular joint proliferation with $\kappa = 0.36$ (fair agreement). The intermethod agreement for the individual observers with regards to the main site of compression was moderate for one observer with $\kappa = 0.49$, and substantial for the other two observers with $\kappa = 0.73$ and $\kappa = 0.68$, respectively. Intermethod agreement for the individual observers ranged from moderate to substantial for the direction and cause of the compression, depending on the observer. A fair to moderate intermethod agreement was found for all three observers for the articular process joint characteristics. For one of the observers, a moderate intermethod agreement was calculated for the presence of foraminal stenosis, whereas for the other two observers the intermethod agreement was slight to fair for the evaluation of foraminal stenosis.

The κ values for the overall interobserver agreement as well as the interobserver agreement between pairs of observers for each individual imaging modality were calculated (Tables 2 and 3). For both CT and MR imaging, the highest interobserver agreement was obtained for the evaluation of the main site of compression. Using CT, the three observers agreed on the main site of compression in 10 of 15 dogs, with a substantial κ agreement, $\kappa = 0.61$. For MR imaging, the three observers agreed on the main site of compression in nine of the 15 dogs, which yielded a moderate agreement with a $\kappa = 0.58$. In general, the three observers agreed on the main site of compression for both CT and MR imaging in those dogs that had severe sites of spinal cord compression (Figs. 1 and 2). In addition, when evaluating CT images two of three observers agreed on the main site of compression for an additional three dogs. Two of the three observers agreed on the main site of compression in an additional five of the 15 dogs when evaluating MR images (Fig. 3). Finally, the three reviewers disagreed on the main site of compression in two dogs when evaluating CT images, and the three reviewers disagreed on the main site of compression in one dog when assessing MR images. For CT, a moderate interobserver agreement was obtained for the direction and cause of compression, with $\kappa = 0.45$ and $\kappa = 0.44$, respectively. For MR imaging, the interobserver agreement was moderate for the direction of compression ($\kappa = 0.44$) and fair for the cause of compression ($\kappa = 0.40$). A fair interobserver agreement was obtained for CT when evaluating the regularity of the right and left articular surfaces ($\kappa = 0.22$ and $\kappa = 0.25$), whereas the interobserver agreement for this feature was slight for MR imaging ($\kappa = 0.06$ and $\kappa = 0.08$). The interobserver agreement for the right and left degree of articular process joint proliferation was slight for CT ($\kappa = 0.09$ and $\kappa = 0.11$) and poor to slight ($\kappa = -0.02$ and $\kappa = 0.01$) for MR imaging. The evaluation of right-sided foraminal stenosis yielded a slight interobserver agreement for both imaging modalities. There was fair interobserver agreement for the evaluation of left-sided foraminal stenosis assessed on CT images, whereas the agreement was slight for MR imaging when evaluating this morphologic feature. All the morphologic features evaluated had a superior overall interobserver agreement when CT images were evaluated compared to MR imaging. For CT imaging, the interobserver agreement for each pair of observers was similar across all three pairwise comparisons for the majority of the morphologic features evaluated with the exception of foraminal stenosis, for which the agreement between observers 1 and 3 yielded higher κ values (Table 2). For MR imaging, the agreement between observers 1 and 3 was consistently higher for the vast majority of the morphologic features evaluated when compared to the interobserver agreement between observers 1 and 2 or 2 and 3 (Table 3).

Discussion

In this prospective study, three observers independently evaluated various morphologic features of the cervical vertebral column of a group of Great Danes affected with cervical spondylomyelopathy that underwent both non-contrast CT and high-field MR imaging. We found that observers frequently agreed with each other in the characterization of the main site of compression when using both of the imaging modalities. However, there was a high degree of intermethod and interobserver variability when evaluating articular joint process characteristics and the presence and degree of foraminal stenosis. The κ values for overall intermethod agreement were superior to the corresponding

TABLE 1. Overall Intermethod Agreement and Intermethod Agreement for Each Observer for Morphologic Features Evaluated Using Noncontrast Computed Tomography and Magnetic Resonance Imaging in 15 Great Danes with Cervical Spondylomyelopathy

Feature	Overall Intermethod	Observer		
Evaluated	Agreement*	1	2	3
Main site of compression	0.65	0.49	0.73	0.68
Direction of compression	0.62	0.69	0.59	0.55
Cause of compression	0.59	0.67	0.53	0.53
Regularity of articular surface (right side)	0.40	0.42	0.30	0.31
Regularity of articular surface (left side)	0.41	0.45	0.26	0.37
Degree of articular joint proliferation (right side)	0.45	0.34	0.42	0.41
Degree of articular joint proliferation (left side)	0.36	0.27	0.27	0.36
Foraminal stenosis (right side)	0.39	0.44	0.20	0.16
Foraminal stenosis (left side)	0.51	0.60	0.34	0.31

*Kappa values are interpreted as follows: almost perfect agreement ($\kappa = 0.81$–1.00), substantial ($\kappa = 0.61$–0.80), moderate ($\kappa = 0.41$–0.60), fair ($\kappa = 0.21$–0.40), slight ($\kappa = 0.00$–0.20), and poor ($\kappa < 0.00$).

TABLE 2. Overall Interobserver Agreement and Interobserver Agreement for Each Pair of Observers for the Morphologic Features Evaluated in 15 Great Danes with Cervical Spondylomyelopathy Using Noncontrast Computed Tomography

Feature	Overall interobserver	Observers		
Evaluated	Agreement*	1 and 2	1 and 3	2 and 3
Main site of compression	0.61	0.68	0.76	0.61
Direction of compression	0.45	0.37	0.48	0.55
Cause of compression	0.44	0.38	0.53	0.47
Regularity of articular surface (right side)	0.22	0.19	0.35	0.23
Regularity of articular surface (left side)	0.25	0.25	0.26	0.31
Degree of articular joint proliferation (right side)	0.09	0.23	0.12	0.04
Degree of articular joint proliferation (left side)	0.11	0.21	0.14	0.08
Foraminal stenosis (right side)	0.16	0.18	0.32	0.13
Foraminal stenosis (left side)	0.23	0.12	0.56	0.10

*Kappa values are interpreted as follows: almost perfect agreement ($\kappa = 0.81$–1.00), substantial ($\kappa = 0.61$–0.80), moderate ($\kappa = 0.41$–0.60), fair ($\kappa = 0.21$–0.40), slight ($\kappa = 0.00$–0.20), and poor ($\kappa < 0.00$).

overall interobserver agreement values for both imaging modalities and for all the morphologic features evaluated, indicating a high degree of variability among observers for both CT and MR imaging. In addition, the overall interobserver agreement values for all the morphologic features evaluated were higher for CT when compared to MR imaging studies.

In this study, the main site of spinal cord compression was the most reliable morphologic feature assessed with substantial intermethod agreement, as well as substantial to moderate interobserver agreement for CT and MR imaging, respectively. However, both intermethod and interobserver agreement values were lower than those obtained when evaluating the main site of compression in similar studies, which compared the use of different imaging modalities to investigate disc-associated cervical spondylomyelopathy.[6,7] The discrepancies noted in the current study when assessing the main site of compression were likely secondary to the presence of multiple affected sites in all the Great Danes imaged, which complicated the

TABLE 3. Overall Interobserver Agreement and Interobserver Agreement for Each Pair of Observers for the Morphologic Features Evaluated in 15 Great Danes with Cervical Spondylomyelopathy Using High-Field Magnetic Resonance Imaging

Feature	Overall Interobserver	Observers		
Evaluated	Agreement*	1 and 2	1 and 3	2 and 3
Main site of compression	0.58	0.61	0.84	0.53
Direction of compression	0.44	0.31	0.54	0.51
Cause of compression	0.40	0.28	0.55	0.44
Regularity of articular surface (right side)	0.08	0.22	0.18	0.03
Regularity of articular surface (left side)	0.06	0.23	0.14	0.007
Degree of articular joint proliferation (right side)	−0.02	−0.03	0.20	−0.04
Degree of articular joint proliferation (left side)	0.01	0.06	0.23	−0.05
Foraminal stenosis (right side)	0.05	0.06	0.36	0.007
Foraminal stenosis (left side)	0.08	0.07	0.42	0.02

*Kappa values are interpreted as follows: almost perfect agreement ($\kappa = 0.81$–1.00), substantial ($\kappa = 0.61$–0.80), moderate ($\kappa = 0.41$–0.60), fair ($\kappa = 0.21$–0.40), slight ($\kappa = 0.00$–0.20), and poor ($\kappa < 0.00$)

evaluation and yielded lower agreement values when compared to those obtained in disc-associated cervical spondylomyelopathy studies, where single compressions are more common.[6,7] Similar discrepancies have been reported in human studies comparing the use of CT and MR images in the assessment of cervical spinal disorders.[11,12,29] In people, the presence of cervical spinal cord compressions at multiple levels has been reported as one of the reasons that explains why observers may show disagreement as to which level has the most severe degree of compression.[29]

Following the main site of compression, the direction and cause of the compression were the next most consistent features evaluated for both intermethod and interobserver agreement, with moderate-to-substantial overall intermethod agreement and fair to moderate interobserver agreement. In a similar study comparing the use of myelography, CT-myelography, and MR imaging in the evaluation of disc-associated cervical spondylomyelopathy, the intermethod and interobserver agreement were very good for the direction of the main site of compression.[7] However, the agreement values were much lower (fair to moderate) when the direction of the additional sites of spinal cord compression was assessed,[7] suggesting that the evaluation of milder compressive sites yields higher variability among observers and when using different imaging modalities. In our study, the direction and cause of compression for all the compressive sites recorded were analyzed together, without differentiating between the direction and cause of the main compressive site and additional compressive sites, which likely explains the intermediate agreement results obtained in our study for these two morphologic features.

Great Danes with osseous-associated cervical spondylomyelopathy frequently show degenerative changes of the cervical vertebral articular process joints.[1,3,4] Our study evaluated the regularity of the articular surfaces and presence of subchondral bone sclerosis, as well as the degree of articular process joint proliferation. These features have been retrospectively evaluated in Great Danes with cervical spondylomyelopathy using MR imaging,[4] but no study comparing CT and MR imaging evaluation of the cervical articular processes in osseous-associated cervical spondylomyelopathy is available. In the evaluation of cervical vertebral column disorders in people, CT is generally considered to be superior to MR imaging for the evaluation of osseous structures.[12,15,18,30] Thus, we hypothesized that CT would be superior than MR imaging at depicting the characteristics of the articular joints. Our results did yield higher overall interobserver agreement values for both the regularity of the articular surfaces and the degree of articular process joint proliferation for CT when compared to MR images. In humans, a recent study compared the ability of noncontrast CT and MR imaging to predict the presence and degree of cervical facet arthrosis and concluded that CT was a better imaging modality for this purpose.[15] However, even if our study showed superior results for CT than MR imaging when evaluating articular joint characteristics, the interobserver agreement values for both of these features were only slight to fair for CT and poor to slight for MR imaging, indicating a high degree of variability among observers. Observers were instructed to grade the articular process joint characteristics from either zero to two or zero to three, depending on the feature assessed. The high degree of interobserver variability likely reflects the subjectivity of this type of grading. It is possible that a more simplified grading scheme indicating whether the articular process joints features were normal (zero) or abnormal (one) could have yielded higher agreements. However, the grading scheme used in this study was chosen following previously published literature.[4] The high degree of interobserver variability probably also reflects how different observers may have an internal subjective standard as to what they believe to be mild, moderate, or severe abnormalities. This is also supported by the fact that the intermethod agreement was superior for the evaluation of the articular process joint characteristics compared to the interobserver agreement of either imaging modality, indicating that observers tended to agree more with themselves regardless of the imaging modality used than with other observers even when using the same imaging modality.

The evaluation of the presence and degree of foraminal stenosis yielded overall intermethod agreement values that ranged from fair to moderate, whereas the interobserver agreements were much lower and ranged from slight to moderate for CT and were slight for MR images. One exception was the interobserver agreement values between observers 1 and 3, which yielded fair-to-moderate interobserver agreement for both CT and MR imaging when evaluating foraminal stenosis. These results indicate a very high degree of interobserver variability when evaluating this morphologic feature, which was also reported in a similar study investigating disc-associated cervical spondylomyelopathy with various imaging modalities.[7] The high variability among observers indicates a high degree of subjectivity and emphasizes that caution should be exerted when comparing results of foraminal stenosis interpreted by different individuals. Our hypothesis that MR imaging would yield superior results when evaluating foraminal stenosis was not proven in this study.

In this study, the overall interobserver agreement values were higher for CT when compared to MR imaging for all the morphologic features evaluated. This may be a reflection of the experience of the observers with these two imaging modalities and more exposure to CT for one of the observers. In fact, the interobserver agreement values obtained for the pair of observers that had more experience with MR imaging (1 and 3) when evaluating this imaging modality were either similar or higher than the equivalent

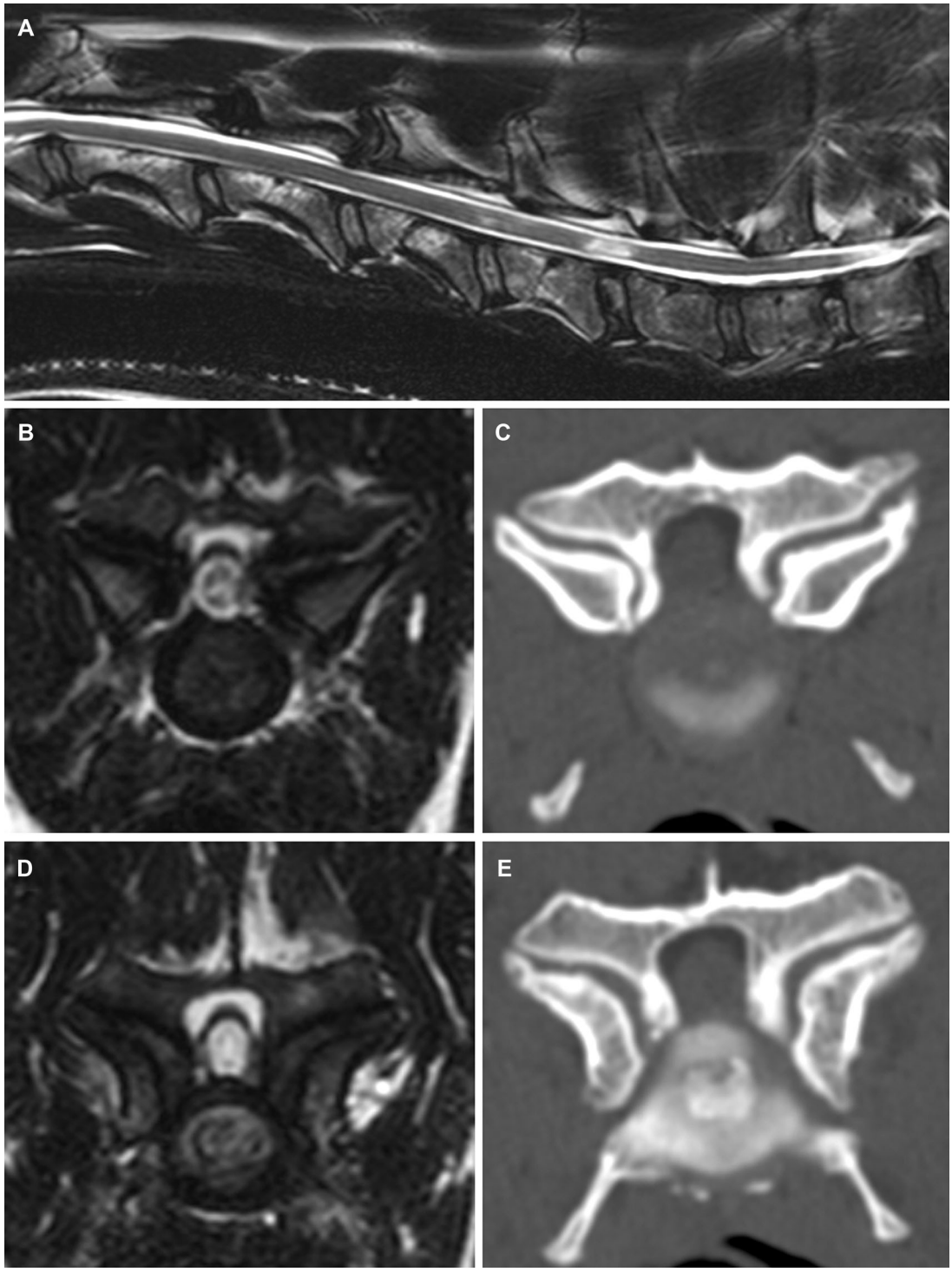

FIG. 1. (A) Mid-sagittal T2-weighted image, (B) transverse T2-weighted image at C5–6 and (C) corresponding transverse noncontrast CT image using a bone window, and (D) transverse T2-weighted image at C6–7 and (E) corresponding transverse noncontrast CT image using a bone window. All three observers determined that the C6–7 intervertebral space was the main site of compression for this dog for both CT and MR imaging studies. The T2-weighted mid-sagittal image reveals two areas of spinal cord hyperintensity at C5–6 (ill-defined, mild) and C6–7 (well-defined, severe), without showing any clear indication of spinal cord compression in this image. Severe proliferation of the pedicles and bilateral lateral articular process joint proliferation with irregular articular surfaces and sclerosis is present at the C5–6 and C6–7 intervertebral spaces, visible on both transverse T2-weighted and CT images. The proliferative articular process joints are causing marked vertebral canal stenosis and severe spinal cord compression, with an elongated appearance of the spinal cord at C6–7. While MR imaging provides information about the severity of the spinal cord signal changes and is suggestive of spinal cord atrophy at C6–7, the CT images more clearly depict the irregular surface and sclerotic changes of the articular processes.

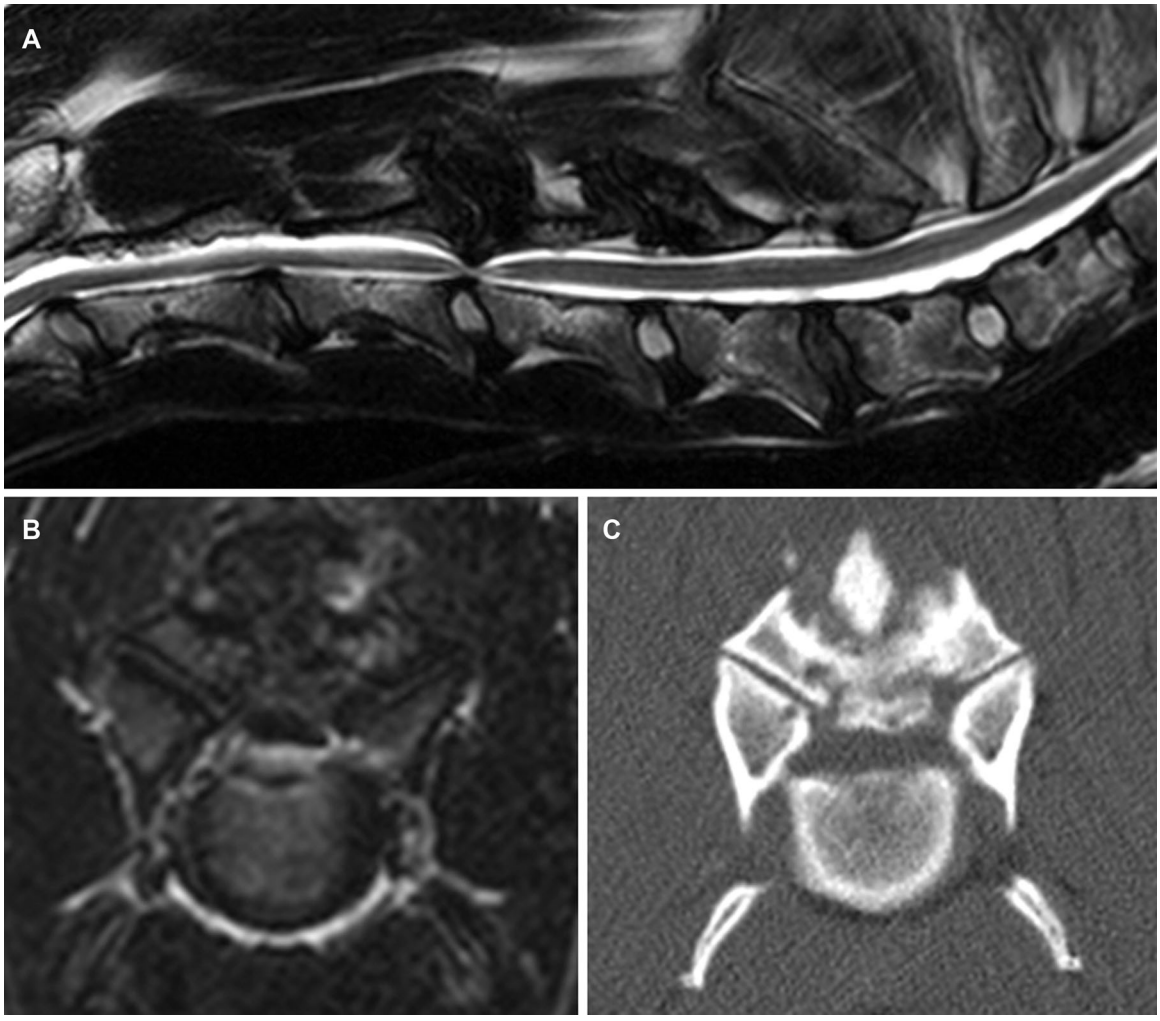

FIG. 2. (A) Mid-sagittal T2-weighted image, (B) transverse T2-weighted image at the C4–5 intervertebral space, and (C) corresponding transverse noncontrast CT image using a bone window. Severe dorsal compression of the spinal cord is present at C4–5 on both mid-sagittal and transverse MR and CT images. All three observers determined that the C4–5 intervertebral space was the main site of compression for this dog for both CT and MR imaging studies. The transverse T2-weighted images show hypointense dorsal tissue hypertrophy as the cause of the compression, consistent with either abnormal proliferative dorsal lamina or ligamentous hypertrophy. The corresponding CT image is supportive of an osseous-associated compression secondary to dorsal lamina proliferation. In this dog, the CT study helped to better define the nature of the hypertrophic tissue causing spinal cord compression.

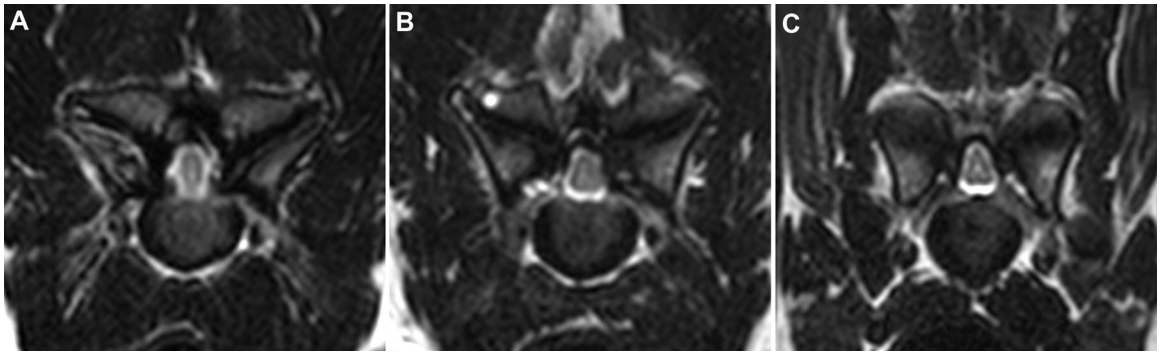

FIG. 3. (A) Transverse T2-weighted images at the C4–5, (B) C5–6, and (C) C6–7 intervertebral spaces of the same dog. Bilateral, lateral spinal cord compression secondary to articular joint process proliferation is present at all levels. Two of the three observers agreed on characterizing C6–7 as the main site of compression. One observer selected the C4–5 intervertebral space as the main site of compression. The presence of multiple, moderate-to-severe compressive sites in several of the dogs enrolled in the study likely resulted in the disagreements noted among different observers when evaluating the main site of spinal cord compression.

agreement values obtained for CT. In human studies, the training and personal experience of the observers is recognized as a factor that can affect the assessment of images in investigations that compare different imaging modalities.[29]

A limitation that is always present in studies that compare various imaging modalities is the experience of the observers.[11] This is also a limitation in this study. Observers had different backgrounds and training, as well as different levels of experience. However, this situation is routinely encountered in the clinical setting, where specialists of various fields (i.e., radiologists and neurologists) and different levels of experience are involved in the decision-making process of cases that undergo advanced imaging. Statistical methods that measure the agreement between two or more observers, such as the κ statistic used in this study, take into account that observers will sometimes agree or disagree simply by chance.[31] For all studies that investigate agreement between observers, it is also important to acknowledge that when comparing two values of κ, a superior value indicates a superior degree of agreement over what would be expected due to chance.[31] Observers were not blinded to patient information and this is also considered a limitation. To minimize possible bias, all observers evaluated the various morphologic features following predetermined grading schemes. Also, in this study no intraobserver agreement was assessed and only transverse plane images were used to evaluate the morphologic features. An additional limitation is the small sample population. However, this was a prospective study with limited funding and time for enrollment of subjects. Ideally, multi-institutional prospective studies that use a previously agreed common imaging protocol including multiple imaging planes and assessing intraobserver agreement would be beneficial. Multi-institutional studies would also allow the enrollment of a larger number of patients. However, studies involving multiple institutions would require similar CT and MR imaging scanners at all of the participating institutions to avoid the fact of different image qualities affecting the evaluation. In our study, the imaging studies for all dogs were acquired with the same CT and MR scanners. The main objective of this study was to compare interobserver and intermethod agreements in the evaluation of cervical spondylomyelopathy and a gold standard was not established, which is a limitation of the study. The majority of the dogs enrolled in this study were medically managed, thus a surgical gold standard was not possible. Moreover, surgical gold standards may be feasible in acute myelopathies with single sites of compression, such as acute intervertebral disc herniation.[22] However, the use of a surgical gold standard becomes more challenging when multiples sites of bony compression are present, as is frequently the case in osseous-associated cervical spondylomyelopathy, since even with dorsal surgical decompression it may be difficult to definitely determine the site of most severe compression, and if a ventral fusion technique is to be applied, it would not allow visualization of the osseous compressive lesions.

In this study, noncontrast CT imaging was performed under sedation. At our facility the MR unit is located off-site, which means that for the enrolled dogs to undergo both CT and MR imaging under anesthesia it would have required two different anesthetic procedures. Thus, we elected to obtain the CT imaging studies under sedation. The CT studies were obtained without complications and all yielded good quality images. The ability to perform noncontrast CT under sedation might facilitate the possibility of pursuing follow-up imaging investigations comparing serial CT studies in order to further characterize the natural history of this disease, as well as long-term follow-up of medically or surgically treated dogs with osseous-associated cervical spondylomyelopathy. While owners may be reluctant to repeatedly anesthetize their pets, they may be more agreeable to repeated imaging as long as this can be pursued under sedation.

In summary, the results of the current study indicate that while different observers frequently agree on the main site of compression when using both noncontrast CT and high-field MR imaging, there is considerable variation between imaging modalities and among observers when assessing articular process characteristics and foraminal stenosis. Computed tomography yielded more consistent results among observers in the evaluation of the cervical articular process joints. The discrepancies noted highlight the need to use caution when comparing image interpretations from multiple observers.

ACKNOWLEDGMENTS

The authors wish to express our gratitude to Marc Hardman for assistance with illustrations and Gary Phillips for assistance with statistical analysis.

REFERENCES

1. Trotter EJ, de Lahunta A, Geary JC, Brasmer TH. Caudal cervical vertebral malformation-malarticulation in Great Danes and Doberman Pinschers. J Am Vet Med Assoc 1976;68:917–930.

2. Chambers JN, Betts CW. Caudal cervical spondylopathy in the dog: a review of 20 clinical cases and the literature. J Am Anim Hosp Assoc 1997;13:571–576.

3. da Costa RC. Cervical spondylomyelopathy. Vet Clin North Am Small Anim Pract 2010;40:881–913.

4. Gutierrez-Quintana R, Penderis J. MRI features of cervical articular process degenerative joint disease in Great Dane dogs with cervical spondylomyelopathy. Vet Radiol Ultrasound 2012;53:304–311.

5. Lipsitz D, Levitski RE, Chauvet AE, Berry WL. Magnetic resonance imaging features of cervical stenotic myelopathy in 21 dogs. Vet Radiol Ultrasound 2001;42:20–27.

6. da Costa RC, Parent JP, Dobson H, et al. Comparison of magnetic resonance imaging and myelography in 18 Doberman pinscher dogs with cervical spondylomyelopathy. Vet Radiol Ultrasound 2006;47:523–531.

7. De Decker S, Gielen IMVL, Duchateau L, et al. Intraobserver, interobserver, and intermethod agreement for results of myelography, computed tomography-myelography, and low-field magnetic resonance imaging in dogs with disk-associated wobbler syndrome. J Am Vet Med Assoc 2011;238:1601–1608.

8. Seim HB, Withrow SJ. Pathophysiology and diagnosis of caudal cervical spondylo-myelopathy with emphasis on the Doberman Pinscher. J Am Anim Hosp Assoc 1982;18:241–251.

9. Sharp NJH, Wheeler SJ, Cofone M. Radiological evaluation of 'wobbler' syndrome – caudal cervical spondylomyelopathy. J Small Anim Pract 1992;33:491–499.

10. Tracy JA, Bartleson JD. Cervical spondylotic myelopathy. Neurologist 2010;16:176–187.

11. Shafaie FF, Wippold II FJ, Gado M, et al. Comparison of computed tomography myelography and magnetic resonance imaging in the evaluation of cervical spondylotic myelopathy and radiculopathy. Spine 1999;24:1781–1785.

12. Song KJ, Choi BW, Kim GH, Kim JR. Clinical usefulness of CT-myelogram comparing with the MRI in degenerative cervical spinal disorders. Is CTM still useful as primary diagnostic tool? J Spinal Disord Tech 2009;22:353–357.

13. Reul J, Gievers B, Weis J, Thron A. Assessment of the narrow cervical spinal canal: a prospective comparison of MRI, myelography and CT-myelography. Neuroradiology 1995;37:187–191.

14. Bartlett RJV, Rowland Hill CA, Devlin R, Gardiner ED. Two-dimensional MRI at 1.5 and 0.5 T versus CT myelography in the diagnosis of cervical radiculopathy. Neuroradiology 1996;38:142–147.

15. Lehman RA, Helgeson MD, Keeler KA, et al. Comparison of magnetic resonance imaging and computed tomography in predicting facet arthrosis in the cervical spine. Spine 2008;34:65–68.

16. Modic MT, Weinstein MA, Pavlicek W, et al. Magnetic resonance imaging of the cervical spine: technical and clinical observations. Am J Radiol 1983;141:1129–1136.

17. Yu YL, du Boulay GH, Stevens JM, Kendall BE. Computed tomography in cervical spondylotic myelopathy and radiculopathy: visualization of structures, myelographic comparison, cord measurements and clinical utility. Neuroradiology 1986;28:221–236.

18. Larsson EM, Holtas S, Cronqvist S, Brandt L. Comparison of myelography, CT myelography, and magnetic resonance imaging in cervical spondylosis and disk herniation. Acta Radiol 1989;30:239.

19. Naganawa T, Miyamoto K, Ogura H, et al. Comparison of magnetic resonance imaging and computed tomogram-myelography for evaluation of cross sections of cervical spinal morphology. Spine 2011;36:50–57.

20. Modic MT, Ross JS, Massaryk TJ. Imaging of degenerative disease of the cervical spine. Clin Orthop Relat Res 1989;239:109–120.

21. Fields EL, Robertson ID, Brown JC Jr. Optimization of contrast-enhanced multidetector abdominal computed tomography in sedated canine patients. Vet Radiol Ultrasound 2012;53:507–512.

22. Cooper JJ, Young BD, Griffin IV JF, et al. Comparison between noncontrast computed tomography and magnetic resonance imaging for detection and characterization of thoracolumbar myelopathy caused by intervertebral disk herniation in dogs. Vet Radiol Ultrasound 2013. doi: 10.1111/vru.12114. [Epub ahead of print]

23. Weishaupt D, Zanetti M, Boos N, Hodler J. MR imaging and CT in osteoarthritis of the lumbar facet joints. Skeletal Radiol 1999;28:215–219.

24. Walraevens J, Liu B, Sloten JV, Goffin J. Qualitative and quantitative assessment of degeneration of cervical intervertebral discs and facet joints. Eur Spine J 2009;18:358–369.

25. da Costa RC, Echandi RL, Beauchamp D. Computed tomography myelographic findings in dogs with cervical spondylomyelopathy. Vet Radiol Ultrasound 2012;53:64–70.

26. da Costa RC, Parent JM, Partlow G, et al. Morphologic and morphometric magnetic resonance imaging features of Doberman Pinschers with and without clinical signs of cervical spondylomyelopathy. Am J Vet Res 2006;67:1601–1612.

27. Fleiss JL, Nee JC, Landis, JR. Large sample variance of kappa in the case of different sets of raters. Psychol Bull 1979;86:974–977.

28. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159–174.

29. Stafira JS, Sonnad JR, Yuh WTC, et al. Qualitative assessment of cervical spinal stenosis: observer variability on CT and MR images. Am J Neuroradiol 2003;24:766–769.

30. Dorenbeck U, Schreyer AG, Schlaier J, et al. Degenerative diseases of the cervical spine: comparison of a multiecho data image combination sequence with a magnetization transfer saturation pulse and cervical myelography and CT. Neuroradiology 2004;46:306–309.

31. Viera AJ, Garrett JM. Understanding interobserver agreement: the kappa statistic. Fam Med 2005;37:360–363.