Magnetic resonance imaging vertebral canal and body ratios in Doberman Pinschers with and without disk-associated cervical spondylomyelopathy and clinically normal English Foxhounds

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Objective—To determine magnetic resonance imaging (MRI) vertebral ratio values representing vertebral canal height, vertebral canal shape, and vertebral body shape in Doberman Pinschers with and without disk-associated cervical spondylomyelopathy (DACSM) and clinically normal English Foxhounds.

Animals—Doberman Pinschers with (n = 18) and without (20) DACSM and clinically normal English Foxhounds (18).

Procedures—All dogs underwent low-field MRI of the cervical vertebral column. From 5 specific measurements made at C3 through C7, 4 linear vertebral ratios were calculated and assessed for correlation: vertebral canal height-to-body height ratio (CBHR), vertebral canal height-to-body length ratio (CBLR), caudal canal height-to-cranial canal height ratio (CCHR), and vertebral body length-to-height ratio (BLHR). The CBHR and CBLR described vertebral canal height, CCHR described vertebral canal shape, and BLHR described vertebral body shape. A midvertebral canal-occupying ratio (mVCOR) for the spinal cord was calculated at C5.

Results—Compared with both groups of unaffected dogs, CBHR, CBLR, and BLHR for Doberman Pinschers with DACSM were significantly smaller. The C7 CCHR was significantly larger in DACSM-affected Doberman Pinschers, compared with clinically normal English Foxhounds. Ratios did not differ significantly between unaffected Doberman Pinschers and clinically normal English Foxhounds. Correlation coefficients between CBHR, CBLR, and mVCOR were low and not significant.

Conclusions and Clinical Relevance—Doberman Pinschers with DACSM had significantly smaller vertebral canal heights and more square-shaped vertebral bodies, compared with unaffected Doberman Pinschers, combined with a funnel-shaped vertebral canal at C7. Breed-specific differences were not evident. Linear MRI vertebral canal-to-body ratios do not appear to predict relative vertebral canal stenosis. (*Am J Vet Res* 2011;72:1496–1504)

In dogs with DACSM, progressive caudal cervical spinal cord compression is typically caused by protrusion of 1 or more intervertebral disks, sometimes in combination with dorsal compression resulting from hypertrophied ligamentum flavum.[1–4] It de-

Abbreviations

BLHR	Vertebral body length-to-height ratio
CBHR	Vertebral canal height-to-vertebral body height ratio
CBLR	Vertebral canal height-to-vertebral body length ratio
CCHR	Caudal vertebral canal-to-cranial vertebral canal height ratio
CSA-SC	Cross-sectional area of the spinal cord
CSA-VC	Cross-sectional area of the vertebral canal
CT	Computed tomography
DACSM	Disk-associated cervical spondylomyelopathy
MRI	Magnetic resonance imaging
mVCOR	Midvertebral canal-occupying ratio
VBH	Vertebral body height
VBL	Vertebral body length
VCHcd	Caudal vertebral canal height
VCHcr	Cranial vertebral canal height
VCHm	Midvertebral canal height

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velops in middle-aged to older dogs of several large breeds, among which adult Doberman Pinschers are overrepresented.[1,5–9]

Although the exact etiopathogenesis of this disorder remains unknown,[1,2] preexisting relative stenosis of the vertebral canal has been suggested as a contributing risk factor for the development of clinical signs.[10–12] This hypothesis is strengthened by the results of several studies,[12,13] which have indicated that the cervical vertebral canal in Doberman Pinschers with clinical signs of cervical spondylomyelopathy is narrower than the cervical vertebral canal in unaffected control dogs. The method of measuring the relative size of the vertebral canal differs among studies.[10,12–16] In several investigations[13,15–21] in humans, dogs, and horses, vertebral canal stenosis has been quantified by use of linear ratios of vertebral canal and vertebral body measurements obtained by use of different diagnostic imaging techniques. Various clinical applications of such ratios have been evaluated in horses with and without stenotic cervical myelopathy[15,21] and recently in Doberman Pinschers with and without clinical signs of cervical spondylomyelopathy.[13]

Although the use of vertebral ratios offers the potential to compare vertebral body and canal dimensions in dogs of different size and conformation,[16] it has been suggested that these ratios are breed specific and that values for one breed should not be extrapolated to other breeds.[20] However, little information is available to confirm or reject the latter hypothesis. The purpose of the study reported here was to determine values of MRI vertebral ratios representing vertebral canal height, vertebral canal shape, and vertebral body shape in Doberman Pinschers with and without DACSM and clinically normal English Foxhounds. The intent was to evaluate whether these ratios were different between dogs of different clinical status and breed. Additionally, a novel vertebral ratio (BLHR) indicative of the shape of vertebral bodies was evaluated. Also, we assessed the correlation of 2 selected linear vertebral ratios (CBHR and CBLR) with the mVCOR, an established ratio describing relative vertebral canal stenosis. This ratio determines the portion of the vertebral canal that is occupied by the spinal cord, thereby providing information regarding the free space available in the vertebral canal at that location.[22] For this purpose, 4 linear vertebral ratios and the mVCOR were calculated in Doberman Pinschers with clinical signs of DACSM, Doberman Pinschers without clinical signs of DACSM, and clinically normal English Foxhounds. It was hypothesized that the assessed vertebral ratios are significantly different between Doberman Pinschers with and without clinical signs, confirming that the vertebral canal is narrower in clinically affected dogs, and between unaffected Doberman Pinschers and clinically normal English Foxhounds, indicating breed specificity of these ratios. Furthermore, it was hypothesized that there is good correlation between the mVCOR and the linear vertebral ratios CBHR and the CBLR, confirming that both linear vertebral ratios can be used as indicators of relative vertebral canal stenosis.

Materials and Methods

Dogs—Fifty-six dogs (Doberman Pinschers and English Foxhounds) were prospectively investigated. Doberman Pinschers were selected for inclusion in the study because of the breed's known predisposition to DACSM. English Foxhounds were selected for inclusion in the study because the breed's body conformation and height at the shoulder region are comparable to that of Doberman Pinschers[23,24] and because of the fact that there is no known predisposition of English Foxhounds to neurologic syndromes affecting the caudal cervical portion of the vertebral column. The experiment was conducted in accordance with the guidelines of the Animal Care Committee of the University of Ghent. For client-owned animals, written consent was obtained from owners prior to enrollment of their dog in the study. The dogs were allocated to 1 of 3 groups on the basis of breed and clinical status as follows: client-owned Doberman Pinschers with clinical signs of DACSM (n = 18), client-owned Doberman Pinschers without clinical signs of DACSM (20), and client-owned (14) and laboratory-owned (4) clinically normal English Foxhounds.

For each dog, physical and complete neurologic examinations, a CBC, and serum biochemical analyses were performed. All Doberman Pinschers underwent an additional echocardiographic examination and evaluation of mucosal bleeding times. All owners of the clinically normal Doberman Pinschers and English Foxhounds were contacted at the end of the study and encouraged to have another neurologic examination performed on their dogs. The goal of this second examination was to evaluate whether the assessed vertebral ratios can be used to predict development of clinical signs in a given period. All neurologic examinations were performed by the same author (SD).

MRI protocol and measurements—A permanent 0.2-T magnet[a] was used to perform MRI in all dogs. All MRI examinations were performed when the dogs were anesthetized. Anesthesia was induced with propofol administered IV and maintained via inhalation of isoflurane in oxygen. Each dog was positioned in dorsal recumbency with its head and neck extended. The forelimbs were fixed parallel to the thoracic wall. The neck was positioned in a joint coil (circular transmit-receive coil) with an inner diameter of 19 cm, and T1-weighted spin echo and T2-weighted fast spin echo images were obtained in the sagittal, dorsal, and transverse planes. The images in the transverse plane were aligned perpendicular to the cervical portion of the spinal cord. Images of the vertebral column were obtained of the vertebral bodies from C2 through C7 in the sagittal and dorsal planes and from C4 through C7 in the transverse plane. The field of view was 29 cm in the sagittal plane, 24 cm in the dorsal plane, and 20 cm in the transverse plane. Slice thickness was 4 mm in the sagittal and dorsal planes and 3 mm in the transverse planes; there was no interslice gap.

All image measurements were performed in randomized sequence by the same author (SD); for each image, the assessor was unaware of the signalment and clinical details of the dog. To allow objective comparison of the sagittal and transverse ratios, the sagittal and transverse measurements were made independently of each other with an interval of at least 1 month between measurement sessions. Measurements were made at the workstation with the available imaging software.[b] The images could be magnified as needed, but all measurements for a given vertebra were made at the same magnification. The accuracy of the measurement tool was calibrated to 0.001 mm and 0.001 mm^2 for linear and circular measurements, respectively. Reliability of linear[25] and circular[26] vertebral column measurements obtained via low-field MRI was determined in previous studies by the authors.

On the midsagittal T1-weighted images of each vertebral body from C3 through C7 obtained from each dog, anatomic locations were identified and the following 5 measurements were performed: VBL, VCHm, VBH, VCHcr, and VCHcd (**Figure 1**). To aid in certain measurements, the dorsal border of the vertebral body was visualized by a line drawn to connect the most craniodorsal and most caudodorsal points of the same vertebral body. The VBL was defined as the distance from the most dorsocranial and most dorsocaudal points of the same vertebral body. The VCHm was defined as the distance from the middle of the dorsal surface of the vertebral body to the closest point of the lamina.[17] The VBH was defined as the distance from the midpoint of the dorsal surface of the vertebral body to the ventral surface of the vertebral body measured parallel to the cranial vertebral endplate. The VCHcr was defined as the distance from the most ventrocranial point of the lamina and the craniodorsal border of the same vertebral body; the VCHcr was measured perpendicular to the dorsal surface of the vertebral body. The VCHcd was defined as the distance from the most dorsocaudal point of the vertebral body to the ventrocaudal point of the lamina of the same vertebra; the VCHcd was measured perpendicular to the dorsal surface of the vertebral body.

From these measurements, the following 4 MRI ratios were calculated for C3 through C7: CBHR, CBLR, CCHR, and BLHR (Figure 1). The CBHR was defined as VCHm divided by VBH. This ratio is suggested to indicate relative vertebral canal stenosis in humans, dogs, and horses.[13,15,17] The CBLR was defined as VCHm divided by VBL. This ratio is also influenced directly by the midsagittal vertebral canal height.[13,15,20] The CCHR was defined as VCHcd divided by VCHcr. This ratio indicates the shape of the vertebral canal in a lateral view; ratios > 1 represent a funnel-shaped vertebral canal that is narrowed cranially.[11,13] The BLHR was defined as VBL divided by VBH. This ratio indicates the shape of the vertebral body; a lower value represents a more square-shaped vertebral body.

On images obtained for each dog, the following 2 measurements were performed at the middle aspect of the C5 vertebra: CSA-VC was measured on transverse T1-weighted images, and CSA-SC was measured on transverse T2-weighted images at the same level (**Figure 2**). From these 2 measurements, the mVCOR of the spinal cord was calculated. This ratio was defined as CSA-SC divided by CSA-VC.[22] The mVCOR determines the portion of the vertebral canal that is occupied by the spinal cord, thereby providing information regarding the free space available in the vertebral canal at that location. The C5 vertebra was selected for these measurements because it was routinely included in the scanning field, and the likelihood of pathological findings that could interfere with the measurements (ie, craniodorsal tilting of the vertebral body and the presence of a funnel-shaped vertebral canal) at this location is considered minimal. Data for a given dog were excluded from these transverse measurements if craniodorsal tilting of the C5 vertebral body or the presence of a funnel-shaped vertebral canal at this location were detected.

Data analysis—The effect of group (Doberman Pinschers with DACSM, Doberman Pinschers without DACSM, or clinically normal English Foxhounds), assessed vertebrae (C3 through C7), sex, and age on the

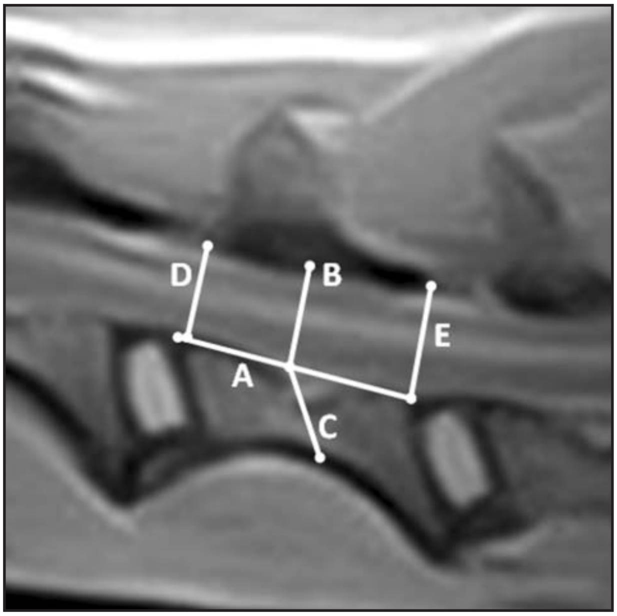

Figure 1—Midsagittal T1-weighted magnetic resonance image of a portion of the cervical vertebral column of a 7-year-old clinically normal English Foxhound illustrating the measurements obtained for C3 through C7 in Doberman Pinschers with and without DACSM and clinically normal English Foxhounds. To aid in certain measurements, the dorsal border of the vertebral body was visualized by a line drawn to connect the most craniodorsal and most caudodorsal points of the same vertebral body. The measurements of interest obtained for each of the cervical vertebrae were VBL (distance between the most dorsocranial and the most dorsocaudal point of the same vertebral body; A), VCHm (distance from the dorsal surface midpoint of the vertebral body to the closest point of the lamina [junction between its laminae and spinous process]; B), VBH (distance between the dorsal surface midpoint and the ventral surface of the vertebral body [measured parallel to the cranial vertebral endplate]; C), VCHcr (distance between the most ventrocranial point of the lamina and the craniodorsal border of the same vertebral body [measured perpendicular to the dorsal surface of the vertebral body]; D), and VCHcd (distance between the most dorsocaudal point of the vertebral body and the ventrocaudal point of the lamina of the same vertebra [measured perpendicular to the dorsal surface of the vertebral body]; E). From these measurements, 4 MRI ratios were calculated for C3 through C7 as follows: CBHR (defined as VCHm [B] divided by VBH [C]), CBLR (defined as VCHm [B] divided by VBL [A]), CCHR (defined as VCHcd [E] divided by VCHcr [D]), and BLHR (defined as VBL [A] divided by VBH [C]). In this dog, the CCHR was approximately 1, which represents a rectangular vertebral canal in a lateral view.

various MRI ratios was evaluated with a mixed model procedure, with the assessed dogs considered as random. All ratios were normally distributed according to results of a Shapiro-Wilk test. Statistical software[c] was used to perform the analyses. *F* tests were used to test for the estimated effect of age on the different ratio values. For this purpose, age was expressed in months. Values of $P < 0.05$ were considered significant. *P* values for multiple comparisons were adjusted by Tukey multiple comparisons procedure.

Box-and-whisker plots of the median values, the 25th and 75th percentiles, and the minimum and maximum values of the 4 calculated ratios in the 3 groups of dogs were created. To evaluate the correlation among the ratios, Pearson correlation coefficients (r) were calculated, and the hypothesis of no correlation ($r = 0$) was tested at the 5% significance level. A perfect correlation would have a value of 1.0, no correlation would have a value of 0, and a perfect inverse correlation would have a value of –1.0. Additionally, regression analysis of values of CBHR and CBLR against the mVCOR of the spinal cord for all dogs was performed. To determine the variation of CBHR and CBLR for specific values of the mVCOR for the spinal cord, 2 intervals were calculated: the 95% confidence interval for the regression line and the 95% confidence interval for observations of CBHR and CBLR for specific values of the mVCOR of the spinal cord (ie, an interval that would include 95% of the observations).

Results

Dogs—Fifty-six dogs (38 Doberman Pinschers and 18 English Foxhounds) were included in the study. Among the Doberman Pinschers, 18 had clinical signs of DACSM and 20 did not have clinical signs of DACSM. The group of affected Doberman Pinschers was comprised of 7 males and 11 females; their ages ranged from 4.4 to 10 years (median age, 7.0 years). These dogs had clinical signs ranging from cervical hyperesthesia only (n = 3) to ambulatory paraparesis and ataxia with or without cervical hyperesthesia (6), ambulatory tetraparesis and ataxia with or without cervical hyperesthesia (7), and nonambulatory tetraparesis with or without cervical hyperesthesia (2). The group of unaffected Doberman Pinschers was comprised of 11 males and 9 females; their ages ranged from 1.5 to 8 years (median age, 5.0 years). Survey radiographic views of 14 of these dogs were also included in a previous study[13] of vertebral ratios. The group of clinically normal English Foxhounds was comprised of 9 males and 9 females; their ages ranged from 1.5 to 12 years (median age, 5.0 years).

CBHR—The CBHR data for C3 through C7 overall and for the individual assessed cervical vertebrae were evaluated for the 3 groups of dogs (**Figure 3**; **Table 1**). There was a significant ($P < 0.001$) overall influence of group on the CBHR. In pairwise comparisons of the C3-C7 data, mean C3-C7 CBHR for Doberman Pinschers with DACSM was significantly smaller, compared with values for unaffected Doberman Pinschers and clinically normal English Foxhounds; however, the mean C3-C7 CBR for unaffected Doberman Pinschers and clinically normal English Foxhounds did not differ significantly. Comparisons among the groups revealed similar findings for the CBHRs at each of the 5 assessed cervical vertebrae. In each group, the CBHR was significantly ($P < 0.001$) influenced by the cervical vertebra under assessment. Within each group, the highest value was evident for C3. For Doberman Pinschers with and without DACSM,

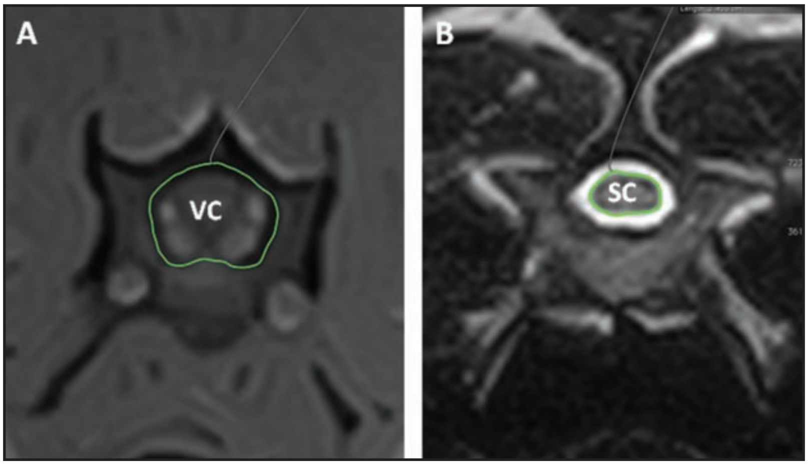

Figure 2—Transverse T1-weighted (A) and T2-weighted (B) magnetic resonance images obtained at the middle aspect of C5 of the same dog as in Figure 1. The mVCOR of the spinal cord was defined as the CSA-SC (B) divided by the CSA-VC (A). This ratio quantifies the portion of the vertebral canal that is occupied by the spinal cord.

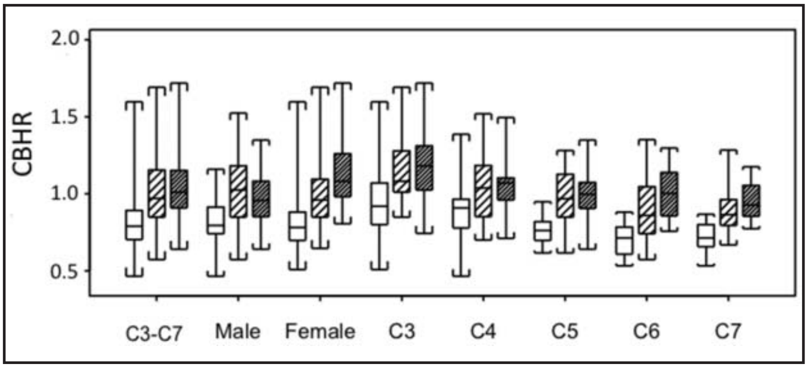

Figure 3—Box-and-whisker plots of the CBHRs determined at the C3 through C7 vertebrae in 18 Doberman Pinschers with clinical signs of DACSM (white boxes), 20 Doberman Pinschers without DACSM (striped boxes), and 18 clinically normal English Foxhounds (dark striped boxes). Data are expressed for the overall C3-C7 CBHR, for the individual vertebrae, and by sex. The distribution of sexes in the 3 groups was as follows: Doberman Pinschers with clinical signs of DACSM, 7 males and 11 females; Doberman Pinschers without DACSM, 11 males and 9 females; and clinically normal English Foxhounds, 9 males and 9 females. For each box, the horizontal line represents the median value, and the upper and lower boundaries represent the 75th and 25th percentiles, respectively. All CBHRs of Doberman Pinschers with DACSM are significantly ($P < 0.05$) smaller for each assessed vertebra, compared with values for Doberman Pinschers without DACSM and clinically normal English Foxhounds. The values for Doberman Pinschers without DACSM and clinically normal English Foxhounds are comparable.

Table 1—Mean values of CBHR, CBLR, CCHR, and BLHR determined at the C3 through C7 vertebrae in 18 Doberman Pinschers with clinical signs of DACSM, 20 Doberman Pinschers without DACSM, and 18 clinically normal English Foxhounds.

Ratio	Overall C3-C7	Male*	Female*	C3	C4	C5	C6	C7
CBHR								
DACSM–affected DPs	0.81^{a}	0.81	0.81	0.95^{a}	0.89^{a}	0.76^{a}	0.71^{a}	0.71^{a}
Unaffected DPs	1.00^{b}	1.01	0.99	1.16^{b}	1.05^{b}	0.98^{b}	0.91^{b}	0.90^{b}
Clinically normal FHs	1.04^{b}	0.97	1.11	1.16^{b}	1.06^{b}	1.00^{b}	1.00^{b}	0.96^{b}
CBLR								
DACSM–affected DPs	0.39^{a}	0.40	0.39	0.31^{a}	0.33^{a}	0.39^{a}	0.43^{a}	0.49^{a}
Unaffected DPs	0.43^{b}	0.44	0.42	0.32^{a}	0.35^{a}	0.42^{b}	0.48^{b}	0.57^{b}
Clinically normal FHs	0.43^{b}	0.42	0.45	0.32^{a}	0.35^{a}	0.41^{b}	0.51^{b}	0.57^{b}
CCHR								
DACSM–affected DPs	1.24^{a}	1.29	1.21	1.27^{a}	1.21^{a}	1.14^{a}	1.21^{a}	1.36^{a}
Unaffected DPs	1.22^{a}	1.24	1.20	1.22^{a}	1.22^{a}	1.15^{a}	1.22^{a}	1.31^{a,b}
Clinically normal FHs	1.22^{a}	1.27	1.18	1.22^{a}	1.24^{a}	1.17^{a}	1.25^{a}	1.23^{b}
BLHR								
DACSM–affected DPs	2.17^{a}	2.13	2.20	3.07^{a}	2.73^{a}	2.00^{a}	1.64^{a}	1.44^{a}
Unaffected DPs	2.47^{b}	2.44	2.50	3.59^{b}	3.01^{b}	2.30^{b}	1.87^{a,b}	1.59^{a}
Clinically normal FHs	2.55^{b}	2.45	2.65	3.63^{b}	3.04^{b}	2.43^{b}	1.97^{b}	1.70^{a}

Data are expressed for the C3 through C7 portion of the vertebral column overall, for individual vertebrae, and by sex.

*The distribution of sexes in the 3 groups was as follows: Doberman Pinschers with clinical signs of DACSM, 7 males and 11 females; Doberman Pinschers without DACSM, 11 males and 9 females; and clinically normal English Foxhounds, 9 males and 9 females.

DP = Doberman Pinscher. FH = English Foxhound.

^{a,b}For each ratio, means in the same column with different superscript letters are significantly ($P < 0.05$) different.

the lowest value was detected at C6 and C7, respectively; for the clinically normal English Foxhounds, the lowest value was detected at C7. There was no significant influence of sex in Doberman Pinschers with ($P = 0.91$) and without ($P = 0.83$) clinical signs of DACSM. In the group of clinically normal English Foxhounds, the CBHR was significantly ($P = 0.043$) smaller in males, compared with females. There was a significant influence of age in Doberman Pinschers with ($P = 0.017$) and without ($P = 0.010$) DACSM. Each increase in age by 1 month resulted in an estimated decrease of CBHR by 0.0027 and 0.0035 for Doberman Pinschers with and without clinical signs, respectively. In the group of clinically normal English Foxhounds, the CBHR was not significantly ($P = 0.22$) influenced by age.

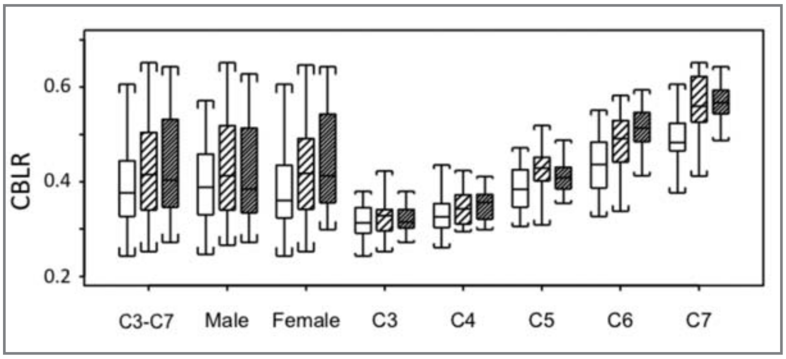

Figure 4—Box-and-whisker plots for CBLRs determined at the C3 through C7 vertebrae in 18 Doberman Pinschers with clinical signs of DACSM (white boxes), 20 Doberman Pinschers without DACSM (striped boxes), and 18 clinically normal English Foxhounds (dark striped boxes). Data are expressed for the overall C3-C7 CBLR, for the individual vertebrae, and by sex. Although the CBLRs of Doberman Pinschers with DACSM are significantly ($P < 0.05$) smaller at the levels of C5, C6, and C7, compared with values for Doberman Pinschers without DACSM and clinically normal English Foxhounds, there is considerable overlap among the various groups. The values for Doberman Pinschers without DACSM and clinically normal English Foxhounds are comparable. *See* Figure 3 for remainder of key.

CBLR—The CBLR data for C3 through C7 overall and for the individual assessed cervical vertebrae were evaluated for the 3 groups of dogs (**Figure 4**; Table 1). There was a significant ($P < 0.001$) overall influence of group on the CBLR. In pairwise comparisons of C3-C7 data, mean C3-C7 CBLR for Doberman Pinschers with DACSM was significantly smaller, compared with values for unaffected Doberman Pinschers and clinically normal English Foxhounds; however, the mean C3-C7 CBLR for unaffected Doberman Pinschers and clinically normal English Foxhounds did not differ significantly. Comparisons among the groups revealed similar findings for the individual CBLRs at C5, C6, and C7 only. In each group, the CBLR was significantly ($P < 0.001$) influenced by the cervical vertebra under assessment. Within each group, CBLR increased from C3 through C7. There was no significant influence of sex in Doberman Pinschers with ($P = 0.440$) and without ($P = 0.450$) clinical signs of DACSM. In the group of clinically normal English Foxhounds, the CBLR was significantly ($P = 0.006$) smaller in males, compared with females. There was a significant ($P = 0.006$) influence of age in unaffected Doberman Pinschers. Each increase in age of 1 month resulted in an estimated decrease of CBLR by 0.0014. There was no significant influence of age in the groups of Doberman Pinschers with clinical signs of DACSM ($P = 0.500$) and clinically normal English Foxhounds ($P = 0.150$).

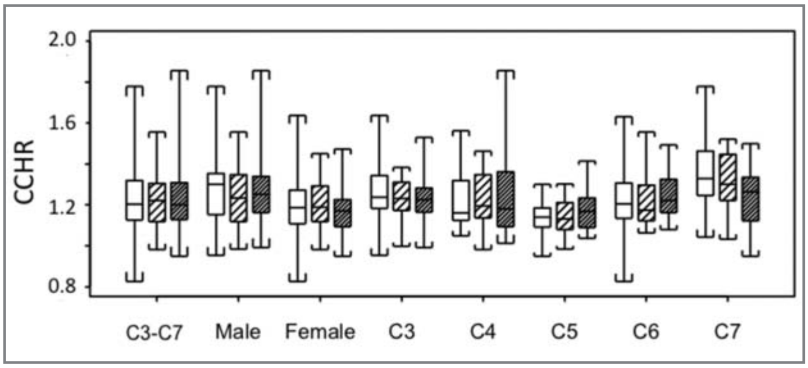

Figure 5—Box-and-whisker plots for CCHRs determined at the C3 through C7 vertebrae in 18 Doberman Pinschers with clinical signs of DACSM (white boxes), 20 Doberman Pinschers without DACSM (striped boxes), and 18 clinically normal English Foxhounds (dark striped boxes). Data are expressed for the overall C3-C7 CCHR, for the individual vertebrae, and by sex. With the exception of the C7 values for Doberman Pinschers with DACSM and clinically normal English Foxhounds, CCHRs are comparable among the various groups. *See* Figure 3 for remainder of key.

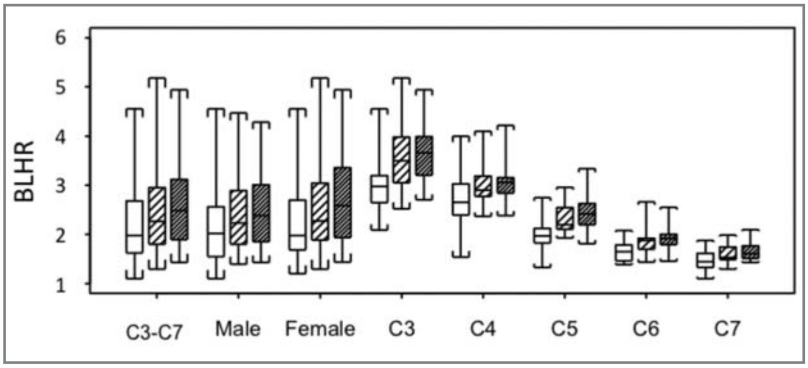

Figure 6—Box-and-whisker plots for BLHRs determined at the C3 through C7 vertebrae in 18 Doberman Pinschers with clinical signs of DACSM (white boxes), 20 Doberman Pinschers without DACSM (striped boxes), and 18 clinically normal English Foxhounds (dark striped boxes). Data are expressed for the overall C3-C7 BLHR, for the individual vertebrae, and by sex. The BLHRs of Doberman Pinschers with DACSM are significantly ($P < 0.05$) smaller at the levels of C3, C4, C5, and C6, compared with values for Doberman Pinschers without DACSM and clinically normal English Foxhounds. The values for Doberman Pinschers without DACSM and clinically normal English Foxhounds are comparable. *See* Figure 3 for remainder of key.

CCHR—The CCHR data for C3 through C7 overall and for the individual assessed cervical vertebrae were evaluated for the 3 groups of dogs (**Figure 5**; Table 1). There was no significant ($P = 0.830$) overall influence of group on the CCHR. In pairwise comparisons of the C3-C7 CCHRs and CCHRs for the individual vertebrae, the only significant difference among groups was that the CCHR for C7 was significantly larger in Doberman Pinschers with clinical signs of DACSM, compared with the C7 CCHR in clinically normal English Foxhounds. In both groups of Doberman Pinschers, the CCHR was significantly ($P < 0.001$) influenced by the cervical vertebra under assessment. The highest value for Doberman Pinschers with ($P = 0.001$) and without ($P < 0.001$) clinical signs of DACSM was evident at C7. In the group of clinically normal English Foxhounds, the CCHR was not significantly ($P = 0.320$) influenced by the cervical vertebra under assessment. There was no significant influence of sex in Doberman Pinschers with ($P = 0.052$) and without ($P = 0.300$) clinical signs of DACSM. In the group of clinically normal English Foxhounds, the CCHR was significantly ($P = 0.032$) larger in males, compared with females. There was a significant influence of age in unaffected Doberman Pinschers ($P = 0.026$) and English Foxhounds ($P = 0.024$). Each increase in age of 1 month resulted in an estimated decrease of CCHR by 0.0014 for unaffected Doberman Pinschers and an increase of CCHR by 0.0013 for clinically normal English Foxhounds. In the group of Doberman Pinschers with DACSM, the CCHR was not significantly ($P = 0.650$) influenced by age.

BLHR—The BLHR data for C3 through C7 overall and for the individual assessed cervical vertebrae were evaluated for the 3 groups of dogs (**Figure 6**; Table 1). There was a significant ($P = 0.002$) overall influence of group on the BLHR. In pairwise comparisons of the C3-C7 data, mean C3-C7 BLHR for Doberman Pinschers with DACSM was significantly smaller, compared with values for unaffected Doberman Pinschers and clinically normal English Foxhounds; however, the mean C3-C7 BLHR for unaffected Doberman Pinschers and clinically normal English Foxhounds did not differ significantly. Comparisons among the groups revealed similar findings for the individual BLHRs at C3, C4, and C5 only. At C6, the BLHR for Doberman Pinschers with or without DACSM did not differ significantly, whereas values for affected Doberman Pinschers and clinically normal English Foxhounds did differ significantly. There was no significant difference in the C7 BLHR among groups at C7. In each of the 3 groups, the BLHR was significantly ($P < 0.001$) influenced by the cervical vertebra under assessment. Within each group, BLHR progressively decreased from C3 through C7. In none of the 3 groups of dogs was the BLHR significantly influenced by sex or age.

Correlation of the CBHR or CBLR with the mVCOR of the spinal cord—The mVCORs in dogs in all 3 groups (n = 56) ranged from 0.16 to 0.30 (mean, 0.25). The Pearson correlation coefficient between the CBHR and the mVCOR was 0.18 ($P = 0.20$), between the CBLR and the mVCOR was 0.057 ($P = 0.68$), and between the CBHR and CBLR was 0.60 ($P < 0.001$). The regression plots with corresponding intervals encompassing 95% of values (**Figure 7**) revealed wide variation of the CBHRs and CBLRs for specific values of the mVCOR of the spinal cord.

Follow-up monitoring—Eighteen of the 20 Doberman Pinschers without DACSM and 9 of the 17 clinically normal English Foxhounds were available for physical and complete neurologic examinations at 16 to 18 months after the MRI examination. These follow-up examinations revealed no abnormalities. The owner

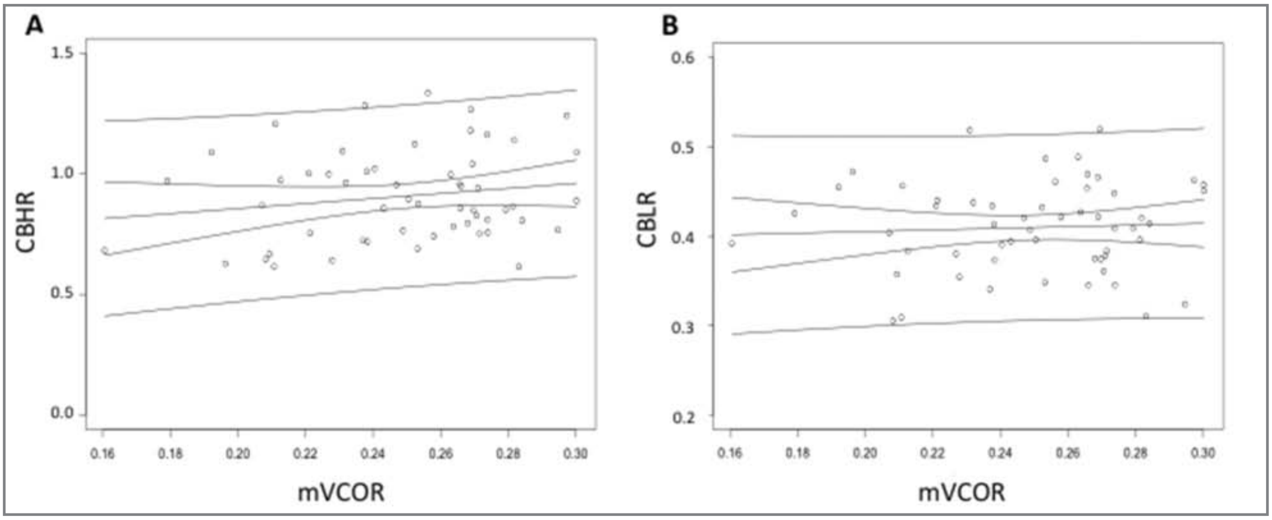

Figure 7—Results of regression analysis of CBHR (A) or CBLR (B) with mVCOR of the spinal cord for 18 Doberman Pinschers with clinical signs of DACSM, 20 Doberman Pinschers without DACSM, and 18 clinically normal English Foxhounds. The middle line corresponds to the regression line, the narrow interval (bounded by lines on either side of the middle line) corresponds to the 95% confidence interval of the regression line, and the broad interval (bounded by the 2 outermost lines) corresponds to the 95% interval for observations of CBHR and CBLR for specific values of the mVCOR (this interval contains 95% of the observations). In each panel, wide variation in CBHR or CBLR for a specific value of the mVCOR is evident.

of 4 other English Foxhounds was available for a telephone interview 9 months after the MRI examination. According to that owner, the dogs were clinically normal. The remaining 2 Doberman Pinschers and 4 English Foxhounds died during the follow-up period for reasons unrelated to this study. According to the owners of those dogs, no clinical signs suggestive of cervical myelopathy had developed in their dogs.

Discussion

Via MRI, values of 4 linear vertebral canal-to-vertebral body ratios were determined in Doberman Pinschers with clinical signs of DACSM, Doberman Pinschers without clinical signs of DACSM, and clinically normal English Foxhounds in the present study. It was hypothesized that these ratios represented relative vertebral canal stenosis, vertebral canal shape, and vertebral body shape.

The results of the present investigation were largely in agreement with those of a recent retrospective study[13] comparing radiographic vertebral canal-to-vertebral body ratios in Doberman Pinschers with and without clinical signs of cervical spondylomyelopathy. The assessed CBHR and CBLR values were significantly smaller in Doberman Pinschers with clinical signs of DACSM, compared with unaffected Doberman Pinschers and clinically normal English Foxhounds. Although the C7 CCHR was largest in Doberman Pinschers with DACSM, lower in unaffected Doberman Pinschers, and lowest in clinically normal English Foxhounds, the only significant difference was that between values for affected Doberman Pinschers and clinically normal English Foxhounds.

In a previous osteologic study,[11] cervical vertebral canal dimensions (after adjustment for different body size) for various dog breeds were determined. Significantly smaller vertebral canal heights were evident in large-breed dogs, compared with findings in small-breed dogs. In the group of large-breed dogs in that study,[11] there was also a significant difference in vertebral canal height between Great Danes and Rottweilers. In the same study, large-breed dogs had larger CCHRs than did small-breed dogs, indicating that the vertebral canal in large-breed dogs was more funnel-shaped. In the group of large-breed dogs, the mean CCHRs at the caudalmost vertebral level evaluated (ie, at C6 and C7) were significantly larger for Doberman Pinschers, compared with the other evaluated breeds.[11] Another study[20] revealed that radiographic cervical vertebral ratios in Great Danes and Doberman Pinschers differed significantly. For these reasons, it is suggested that vertebral ratio values are breed specific and that values for one breed should not be extrapolated to other breeds.[20] This hypothesis could not be confirmed in the present study; the values of the evaluated ratios for Doberman Pinschers without DACSM and clinically normal English Foxhounds were not significantly different. However, it should be emphasized that only 2 breeds, albeit with comparable body conformation, were included in this study. Inclusion of additional breeds and in particular small-breed dogs could have altered the results. This speculation is supported by results of another radiographic study[16] in which a significant difference in a cervical spinal cord-to-vertebral canal ratio was detected between large- and small-breed dogs.

In the present study, we evaluated a novel vertebral ratio: the BLHR. It was assumed that this ratio provided an indication of the shape of a vertebral body. Significantly smaller overall BLHRs, indicative of more square-shaped vertebral bodies, were evident in Doberman Pinschers with clinical signs of DACSM, compared with findings in unaffected Doberman Pinschers and clinically normal English Foxhounds. Although the clinical relevance of this finding is currently unknown, it seems plausible that differences in vertebral body shape may alter the biomechanical properties of the cervical vertebral column.[27] It is suspected that a decrease in length of the cervical vertebral bodies, implying a lower radius of action in intervertebral motion, results in an increase in range of motion during flexion and extension.[27–29] The fact that vertebral body dimensions are significantly different between dogs with and without clinical signs of DACSM questions the reliability of vertebral canal-to-body ratios to quantify relative vertebral canal stenosis. After all, the 2 ratios that reflect vertebral canal stenosis, CBHR and CBLR, are not only affected by the VCHm, but also directly by the height and length, respectively, of the vertebral body.

These concerns were confirmed by the very low and nonsignificant correlation coefficient between the CBHR or CBLR and the mVCOR, which suggested that both assessed linear vertebral ratios are of limited value in predicting relative vertebral canal stenosis. Relative vertebral canal stenosis was quantified by the proportion of the vertebral canal that was occupied by the spinal cord.[22] To better understand the rationale for investigating the mVCOR, understanding the concept of relative vertebral canal stenosis is necessary. In relative vertebral canal stenosis, the vertebral canal diameter is less than what would be considered normal but does not cause spinal cord compression in itself.[11,30] It is associated with a decreased amount of available free space between the spinal cord and the bony vertebral canal,[22,30] which may become clinically relevant depending on development of degenerative space-occupying conditions of the vertebral canal.[30] From this point of view, it is clear that relative vertebral canal stenosis is dependent on 2 variables, the CSA-SC and the CSA-VC. In the authors' opinion, this justifies the choice of the mVCOR to quantify relative vertebral canal stenosis.

In addition to the fact that the CBHR and CBLR are dependent on potentially variable vertebral body dimensions, the inability of linear vertebral canal-to-vertebral body ratios to reliably predict relative vertebral canal stenosis may have other explanations. First, it is obvious that the dimensions of the vertebral canal are dependent on both the sagittal and transverse dimensions of the vertebral canal.[31] Both linear vertebral ratios take only the sagittal vertebral canal height into account. Second, relative vertebral canal stenosis is dependent on the dimensions of the vertebral canal and the spinal cord.[22] The spinal cord diameter is not taken into account by the assessment of either of these linear vertebral canal-to-vertebral body ratios.

Because the results of the present study indicated that the CBHR and CBLR do not predict relative vertebral canal stenosis in dogs, questions arise regarding clinical interpretation of these ratios. Both of these vertebral canal-to-vertebral body ratios are directly dependent on the midsagittal vertebral canal height. Therefore, it is maybe more prudent to consider the CBHR and CBLR as determinants of the midsagittal height of the vertebral canal.[32] A study[33] comparing CBHRs, vertebral canal heights, and VBHs (ie, anteroposterior diameter) as 3 separate variables in people with and without clinical signs of cervical spondylomyelopathy revealed that patients with cervical myelopathy had not only smaller CBHR values and a narrower sagittal cervical canal diameter, but also a wider vertebral body diameter than did people in the control population.[33] This explains the significant difference in CBHRs between both groups of people and additionally suggests that not only a narrow sagittal vertebral canal, but also the combination of a narrow sagittal vertebral canal and a wide vertebral body are risk factors for development of cervical myelopathy in humans.[33] Although significantly smaller BLHRs, suggesting relative wider vertebral bodies, were evident in Doberman Pinschers with DACSM, compared with values in Doberman Pinschers without DACSM and clinically normal English Foxhounds, more studies are warranted to investigate whether there is a similar relationship in dogs.

In the present study, dogs underwent low-field MRI and measurements were made on the images obtained. A recent study[25] performed by our group revealed very good agreement and repeatability of linear vertebral body and canal measurements by use of low-field MRI. In that study,[25] low-field MRI was superior to CT for that purpose. This finding could be attributed to loss of detail and partial volume averaging during the sagittal reconstruction process associated with CT, which resulted in increased variability and a disturbing overestimation of linear measurements in the reconstructed CT plane (z-axis). As a consequence, CT proved to be less useful for the assessment of VBL.[25]

None of the dogs of either breed that were considered normal developed clinical signs of cervical hyperesthesia or myelopathy during the follow-up period in the present study. However, the number of dogs available for follow-up was rather small and they were only monitored for a limited period. This makes it difficult or even impossible to draw reliable conclusions about the predictive value of the assessed vertebral ratios. Furthermore, it has already been shown that the application of vertebral ratios in individual animals to differentiate between clinically affected and clinically normal dogs is currently inappropriate.[13] This recommendation is supported by the results of the present study. Analysis of the constructed box-and-whisker plots revealed considerable overlap in ratio values, although to a lesser extent for CBHR, among the different groups of dogs.

The results of the present study supported the hypothesis of altered vertebral canal and vertebral body dimensions in Doberman Pinschers with clinical signs of DACSM, as determined via MRI. However, breed specificity of the assessed MRI vertebral ratios could not be demonstrated and the CBHR and CBLR do not predict relative vertebral canal stenosis as was suggested in previous studies. Considering the fact that results of several studies in dogs,[13] horses,[15,21] and humans[17,19,33,34] have indicated that vertebral canal-to-vertebral body ratios in clinically affected individuals are significantly lower than the corresponding values in clinically normal individuals, further studies are warranted to ascertain how vertebral canal-to-vertebral body ratios in dogs should be interpreted.

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a. Magnet, Airis Mate, Hitachi, Tokyo, Japan.
b. Osirix, Los Angeles, Calif.
c. Proc MIXED, SAS, version 9.2, SAS Institute Inc, Cary, NC.

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