THE EFFECT OF ANGLE SLICE ACQUISITION ON COMPUTED TOMOGRAPHIC CERVICAL VERTEBRAL COLUMN MORPHOMETRY IN GREAT DANES

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Computed tomography (CT) scans can be acquired with the transverse images aligned either parallel to the endplates or perpendicular to the vertebral canal. The purpose of this prospective cross-sectional study was to determine the effect of angle acquisition on CT morphometric evaluation of the cervical vertebral column of Great Danes with and without cervical spondylomyelopathy. Twenty-eight Great Danes (13 normal, 15 affected) were sampled. For each dog, a set of CT images was acquired with the transverse slices aligned parallel to the endplates and another one with the transverse images aligned perpendicular to the vertebral canal. For each different set, transverse slices from the cranial, middle, and caudal aspects of the individual vertebral bodies C2-C7 were measured. Height, width, transverse area, right dorsal to left ventral height (RDLV), and left dorsal to right ventral height (LDRV) were recorded by a single observer at each location. For both affected and control dogs, significant differences between the measurements obtained from the two sets of transverse images were found only at the cranial aspect of the vertebrae ($P = 0.005$, $P < 0.001$, $P < 0.001$, $P = 0.005$, and $P = 0.010$ for height, width, area, RDLV, and LDRV, respectively). Measurements for the middle and caudal aspects did not differ. The funnel-shape morphology of the cervical vertebral foramina in Great Danes with stenosis of their cranial aspect may be responsible for the significant differences found. Considering that the morphometric parameters were significantly affected by CT slice angle in the current study, authors recommend that a standardized scanning protocol be followed when morphometric evaluations using CT are planned.

Key words: Angle, cervical spondylomyelopathy, computed tomography, dog, imaging.

Introduction

Cervical spondylomyelopathy, a condition commonly known as Wobbler Syndrome, is the most common disease of the cervical vertebral column of large and giant dog breeds.[1–3] Cervical spondylomyelopathy is caused by the presence of cervical spinal cord compression and manifests as neurologic deficits and neck pain.[1,2,4] Great Dane dogs often become affected at a young age as they develop lateral or dorsolateral cervical spinal cord compression due to osseous proliferations or malformations.[1–6] The most common sites of compression have been found to be at C5-C6 and C6-C7.[2,4–6]

A number of magnetic resonance (MR) imaging morphometric studies have been completed to further characterize the disease process, pathogenesis, and diagnosis of cervical spondylomyelopathy.[1,6–8] Recently, an MR imaging cervical morphometric study in Great Danes showed that Great Danes with cervical spondylomyelopathy have significantly greater vertebral canal and foraminal stenosis throughout the entire cervical vertebral column than clinically normal Great Danes.[6] Another MR imaging morphometric study in Doberman Pinschers and English Foxhounds showed that spinal cord compression can be present in clinically normal dogs, but clinical signs are unlikely to arise unless a critical degree of spinal cord compression is reached.[7] Good agreement has been demonstrated between cervical vertebral measurements obtained via MR

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imaging and computed tomography (CT).[8] However, when compared to MR imaging, there is little information in the literature regarding CT morphometric studies of the cervical vertebral column in dogs. There have been morphometric CT studies of the lumbosacral vertebral column in dogs with and without lumbosacral stenosis,[9,10] but morphometric CT studies of the cervical vertebral column have only very recently come to surface in veterinary literature.[11] For example, cervical CT myelography was recently used to evaluate height, width, and area of the vertebral canal and spinal cord of normal dogs and determined that the ratio of spinal cord area to vertebral canal area is larger in small dog breeds than in larger breeds.[11] The authors are unaware of any cervical CT morphometric studies performed in giant breed dogs to date.

Noncontrast CT can be used to evaluate dogs suspected of having cervical spondylomyelopathy, although it cannot necessarily be used alone to establish a definitive diagnosis.[3,12] It is common in clinical practice that cervical CT scans be acquired with the transverse images aligned either parallel to the endplates or perpendicular to the vertebral canal. When evaluating for intervertebral disk disease, it has been suggested that the CT gantry be oriented such that the transverse images are obtained parallel to the endplates; otherwise the images should be obtained perpendicular to the vertebral canal.[3] There is little literature regarding angle acquisition during CT and MR imaging and the resultant effect on cross-sectional morphometry of the cervical vertebral column. A published morphometric CT study did not mention the angle at which the images were acquired during scanning.[11] Further, the angle at which the transverse images were obtained in MR imaging morphometric studies varies. For example, in two studies the transverse MR images were aligned parallel to the endplates,[1,6] while in another study, the transverse images were aligned perpendicular to the spinal cord.[7] This leads us to question if we can reliably relate the results of these various studies because we do not yet know the effect that angle acquisition has on cross-sectional morphometry of the vertebral canal and spinal cord. Previous human studies have indicated that obtaining oblique cuts during CT imaging would result in larger cross-sectional measurements.[13,14] However, another study that was conducted using artificially manufactured spinal phantoms demonstrated that the vertebral canal can actually appear more stenotic when imaged obliquely.[15] Thus, the purposes of this study were to determine the effect of angle acquisition on CT cervical morphometry in Great Danes, and to compare the cervical vertebral column morphometry in clinically normal Great Danes and Great Danes with cervical spondylomyelopathy. We hypothesized that the measurements obtained from transverse slices acquired parallel to the endplates would be larger than those acquired perpendicular to the vertebral canal.

Methods

This study was conducted in accordance with the guidelines and with approval of The Ohio State University Clinical Research Advisory Committee and the Institutional Animal Care and Use Committee. Twenty-eight client-owned Great Danes over 1 year of age, 13 clinically normal (control) and 15 with cervical spondylomyelopathy, were prospectively enrolled between April 2011 and October 2012. Written client consent was obtained prior to enrollment and all dogs were evaluated by two investigators (RCdC and PMV). All dogs underwent physical examination, neurologic examination, complete blood counts, serum biochemical profiles, and cervical CT and MR imaging. Affected Great Danes were included if they had clinical signs consistent with a cervical myelopathy, and CT and MR imaging findings consistent with cervical spondylomyelopathy. Control Great Danes were included if they had a normal neurologic examination and no previous history of neurologic disease. Control dogs were excluded if neurologic deficits were found on examination.

All Great Danes underwent the same CT scanning protocol. All dogs were sedated with dexmedetomidine (4–8 mcg/kg IV, Dexdomitor®, Pfizer Animal Health, New York, NY) and hydromorphone (0.05–0.1 mg/kg IV, West-Ward Pharmaceuticals, Eatontown, NJ) and placed in sternal recumbency with the head and neck in a neutral position. Noncontrast CT studies were obtained using an 8-slice helical scanner (GE LightSpeed Ultra 8-slice, GE Healthcare, Waukesha, WI). Slice thickness was set at 2.5 mm. Images were obtained from C2-C3 to T2-T3. Using an axial scanning mode, two sets of CT images were obtained: first with the transverse images aligned parallel to the endplates, then with the transverse images aligned perpendicular to the vertebral canal (Fig. 1). Technique settings used were 120 kV, automatic mA (min = 100 mA), 50-cm scan field, 512×512 matrix, bone algorithm, and 6.25-mm/s table speed.

All measurements were made from transverse slices by a single observer (AMJ) trained by the senior investigator, using a dedicated workstation and software program for medical imaging analysis (ClearCanvas Workstation, ClearCanvas Inc., Toronto, ON, Canada). Measurements were repeated twice. For each scan, measurements were obtained from the caudal aspect of C2 through C7. With the exception of C2, measurements were made at three locations along each vertebra, including cranial, middle, and caudal locations. Locations for measurement were kept consistent across scans by following the protocol defined in Table 1. If motion artifact was present through a slice of interest, the slice cranial or caudal was used in its place. At each vertebral location, height, width, and transverse area of the vertebral foramen were measured (Fig. 2). Because Great Danes often suffer from dorsolateral cervical spinal

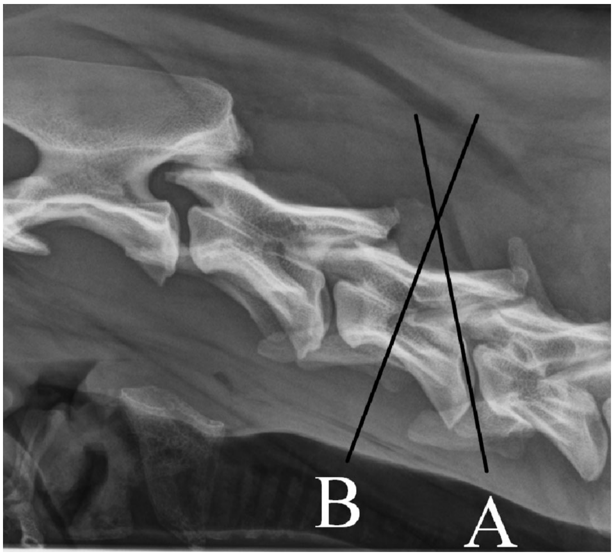

FIG. 1. Canine lateral cervical radiograph demonstrating the orientation of transverse slices used when acquiring CT or MR images. Images can be obtained (A) parallel to the endplates or (B) perpendicular to the vertebral canal.

TABLE 1. Selection Protocol for Obtaining Computed Tomographic Cervical Vertebral Foraminal Measurements

Vertebra	Location	Transverse Image Measured
C2	Caudal	Last image where the vertebral foramen was readily visualized
C3-C5	Cranial	1st image where the vertebral foramen & transverse foramina were readily visualized
	Middle	Last image where the transverse foramina were readily visualized
	Caudal	Last image where the vertebral foramen was readily visualized
C6	Cranial	1st image where the vertebral foramen was readily visualized
	Middle	Last image where the transverse foramina were readily visualized
	Caudal	Last image where the vertebral foramen was readily visualized
C7	Cranial	1st image where the vertebral foramen was readily visualized
	Middle	Halfway between cranial and caudal slices; more caudal if odd number of images
	Caudal	Last image where the vertebral foramen was readily visualized

cord compressions,[4,16,17] measurements were also taken of both the left dorsal to right ventral height (LDRV) and the right dorsal to left ventral height (RDLV), as shown in Fig. 2. Right and left foraminal heights were also measured (Fig. 3).

Vertebral foraminal measurements were made by first drawing a reference line that bisected the spinous process and vertebral body (Fig. 2). If one or the other were not visible in an individual image, the line bisecting the other was extended straight up or down. The height of the vertebral foramen was measured along this reference line. The width of the foramen was measured at a 90° angle to the reference line so that the height and width would intersect at the center of the foramen. LDRV and RDLV height measurements were made to intersect at this same point, at a 90° angle to one another and a 45° angle to the reference line. The transverse area was measured at each location by making a tracing around the vertebral foramen. Intervertebral foraminal height measurements were also taken at each endplate throughout the cervical vertebral column (Fig. 3). These measurements were taken from the image at each endplate where the articular facets, vertebral body, and intervertebral foramina were most readily visualized. Again, a line bisecting the spinous process and vertebral body was drawn and used as a reference line (Fig. 3). Right and left intervertebral foraminal height was measured near the middle of each foramen at a 45° angle to the reference line and a 90° angle to each other, such that if their lines were extended they would intersect on the reference line.

Statistical analysis was performed by a professional biostatistician using commercially available software (Stata, version 12.1, Stata Corporation, College Station, TX). For the control dogs, the measurements of vertebral foraminal height, width, area, RDLV and LDRV, and foraminal height were analyzed using separate random-effects linear regression models for each location (cranial, middle, caudal, and each endplate). *P*-values and 95% confidence intervals (CI) were adjusted using the Sidak method in order to conserve the overall type 1 error at 0.05 for each outcome measurement due to the multiple comparisons ($P<0.05$ was considered significant). The same statistical analysis was performed for the group of affected Great Danes. Then, the combined data from the control and affected groups were analyzed in the same manner. Separate random-effects linear regression models were then used to compare the measurements obtained from the affected dogs to those of the control dogs for each angle of acquisition (transverse images aligned parallel to the endplates versus transverse images aligned perpendicular to the vertebral canal). Lastly, measurements from two affected Great Danes and two normal Great Danes were repeated three months later by the same investigator (AMJ) and a random-effects maximum likelihood linear regression model was used to evaluate intraobserver agreement.

Results

The control group included six spayed females, six neutered males, and one intact male. The mean age at the time of enrollment was 2.3 years (range 1.2–6.3 years) with a mean weight of 53.4 kg (range 40.5–73.0 kg). The affected group included two spayed females, twelve neutered males,

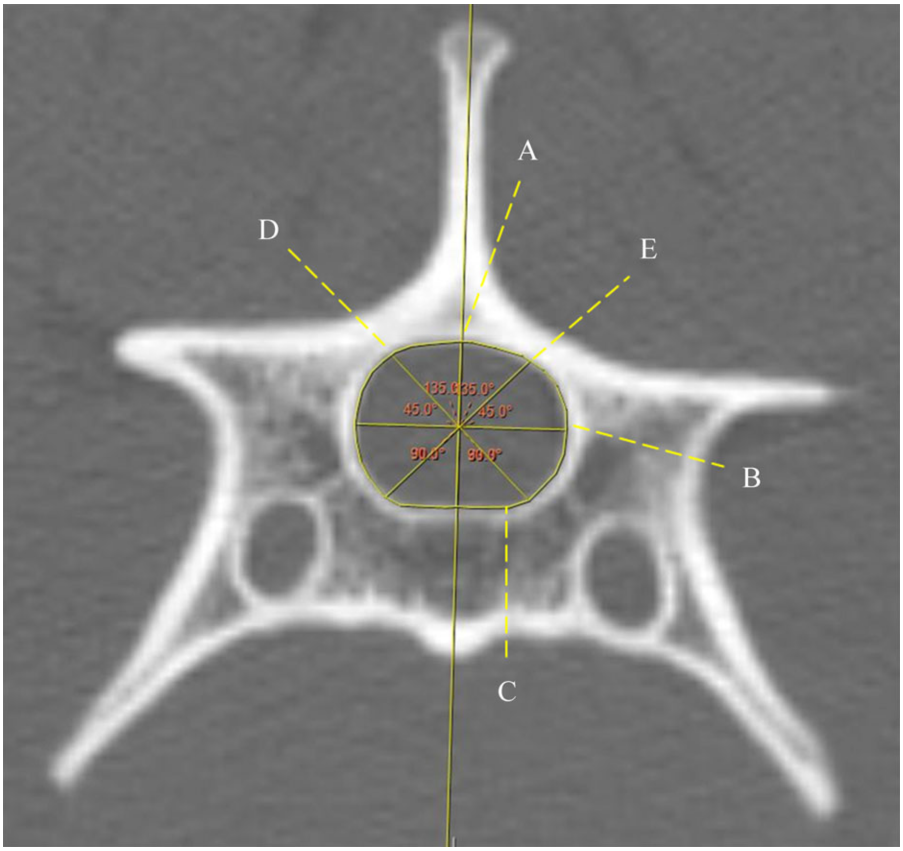

FIG. 2. Transverse CT image illustrating (A) height, (B) width, (C) area, (D) LDRV, and (E) RDLV measurements.

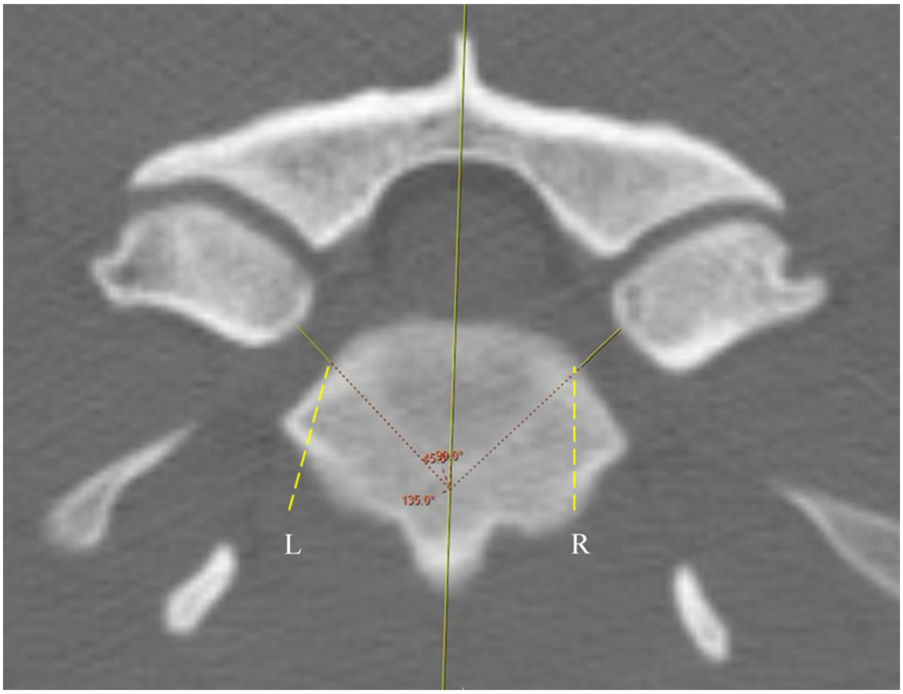

FIG. 3. Transverse CT image illustrating right (R) and left (L) intervertebral foraminal height measurements.

TABLE 2. Vertebral Column Measurements in Control Great Danes When Measured on Transverse Cervical CT Images Oriented Parallel to the Endplates and Perpendicular to the Vertebral Canal

Assessed Variable		Mean Value Parallel (cm)	Mean Value Perpendicular (cm)	Difference	Sidak (95% CI)		Sidak *P*-value
Height	Cranial	1.070	1.029	−0.041	−0.090	0.007	0.121
	Middle	1.136	1.145	0.009	−0.040	0.057	0.964
	Caudal	1.255	1.266	0.011	−0.034	0.056	0.912
Width	Cranial	1.764	1.671	−0.093	−0.136	−0.049	<0.001*
	Middle	1.502	1.515	0.013	−0.030	0.057	0.843
	Caudal	1.551	1.584	0.033	−0.008	0.073	0.152
Area	Cranial	1.556	1.441	−0.115	−0.173	−0.058	<0.001*
	Middle	1.599	1.621	0.022	−0.035	0.080	0.732
	Caudal	1.867	1.913	0.046	−0.007	0.099	0.116
RDLV[†]	Cranial	1.341	1.300	−0.041	−0.076	−0.006	0.014*
	Middle	1.414	1.426	0.012	−0.023	0.046	0.806
	Caudal	1.646	1.660	0.014	−0.018	0.046	0.630
LDRV[‡]	Cranial	1.341	1.299	−0.042	−0.078	−0.007	0.013*
	Middle	1.412	1.432	0.020	−0.015	0.056	0.436
	Caudal	1.644	1.652	0.008	−0.025	0.040	0.927
L Foraminal Height		0.482	0.505	0.023	−0.009	0.054	0.155
R Foraminal Height		0.479	0.504	0.024	−0.013	0.062	0.203

[*] $P < 0.05$ considered significant; CI = confidence interval; Difference = contrast between parallel and perpendicular measurements; [†] Right dorsal to left ventral height; [‡] Left dorsal to right ventral height.

TABLE 3. Vertebral Column Measurements in Great Danes with Cervical Spondylomyelopathy When Measured on Transverse Cervical CT Images Oriented Parallel to the Endplates and Perpendicular to the Vertebral Canal

Assessed Variable		Mean Value Parallel (cm)	Mean Value Perpendicular (cm)	Difference	Sidak (95% CI)		Sidak *P*-value
Height	Cranial	1.075	1.027	−0.048	−0.096	−0.000	0.048*
	Middle	1.188	1.148	−0.040	−0.088	0.008	0.128
	Caudal	1.296	1.327	0.032	−0.013	0.077	0.257
Width	Cranial	1.706	1.631	−0.074	−0.124	−0.024	0.011*
	Middle	1.505	1.506	0.001	−0.048	0.051	>0.99
	Caudal	1.406	1.394	−0.013	−0.059	0.034	0.887
Area	Cranial	1.552	1.442	−0.110	−0.181	−0.039	<0.001*
	Middle	1.673	1.636	−0.038	−0.109	0.034	0.502
	Caudal	1.703	1.725	0.022	−0.044	0.089	0.809
RDLV[†]	Cranial	1.373	1.330	−0.043	−0.085	−0.001	0.044*
	Middle	1.463	1.455	−0.008	−0.050	0.034	0.961
	Caudal	1.553	1.561	0.008	−0.032	0.047	0.954
LDRV[‡]	Cranial	1.342	1.309	−0.033	−0.072	0.005	0.116
	Middle	1.454	1.436	−0.018	−0.057	0.020	0.595
	Caudal	1.537	1.542	0.005	−0.031	0.042	0.979
L Foraminal Height		0.301	0.338	0.037	0.001	0.073	0.047*
R Foraminal Height		0.283	0.317	0.034	−0.002	0.070	0.065

[*] $P < 0.05$ considered significant; CI = confidence interval; Difference = contrast between parallel and perpendicular measurements; [†] Right dorsal to left ventral height; [‡] Left dorsal to right ventral height.

and one intact male. The mean age at the time of enrollment in the study was 3.9 years (range 1–7.2 years) with a mean weight of 57.8 kg (range 42.0–79.3 kg). The affected dogs had displayed clinical signs for a mean of 1.9 years (range 0–5 years) before enrollment in the study and clinical signs had started at a mean age of 1.8 years (range 0.4–4.2 years).

The control group revealed significant differences in width, area, LDRV, and RDLV based on angle acquisition (Table 2). In the Great Danes with cervical spondylomyelopathy, significant differences in height, width, area, RDLV, and left foraminal height were found when measurements were acquired at different angles (Table 3). In both control and affected groups, the significant differences were identified only when these measurements were obtained at the cranial aspect of the vertebrae. When the measurements of both control and affected Great Danes were combined (Table 4), the height measured on the transverse images acquired parallel to the endplate was significantly larger than that measured on the transverse images acquired perpendicular to the vertebral canal, but only at the cranial locations ($P = 0.005$). The same was found for width ($P < 0.001$), area ($P < 0.001$), RDLV ($P = 0.005$), and LDRV ($P = 0.010$), for which the vertebral foraminal measurements acquired at different angles varied significantly only at the cranial aspect of the vertebrae. At these locations, the measured variables obtained from the combined group

TABLE 4. Vertebral Column Measurements in Great Danes with Cervical Spondylomyelopathy and Control Great Danes When Measured on Transverse Cervical CT Images Oriented Parallel to the Endplates and Perpendicular to the Vertebral Canal

Assessed Variable		Mean Value Parallel (cm)	Mean Value Perpendicular (cm)	Difference	Sidak (95% CI)		Sidak *P*-value
Height	Cranial	1.073	1.027	−0.046	−0.081	−0.011	0.005*
	Middle	1.165	1.146	−0.019	−0.054	0.016	0.285
	Caudal	1.278	1.301	0.023	−0.010	0.055	0.256
Width	Cranial	1.731	1.650	−0.081	−0.117	−0.046	<0.001*
	Middle	1.503	1.511	0.008	−0.028	0.043	0.935
	Caudal	1.471	1.476	0.005	−0.028	0.038	0.982
Area	Cranial	1.554	1.444	−0.110	−0.161	−0.059	<0.001*
	Middle	1.639	1.630	−0.009	−0.060	0.042	0.967
	Caudal	1.776	1.806	0.030	−0.018	0.077	0.353
RDLV†	Cranial	1.358	1.318	−0.040	−0.071	−0.010	0.005*
	Middle	1.440	1.443	0.002	−0.028	0.033	0.997
	Caudal	1.595	1.603	0.009	−0.019	0.037	0.839
LDRV‡	Cranial	1.342	1.306	−0.036	−0.065	−0.007	0.010*
	Middle	1.435	1.435	0.000	−0.029	0.029	>0.999
	Caudal	1.585	1.590	0.005	−0.022	0.032	0.963
L Foraminal Height		0.383	0.412	0.029	0.000	0.057	0.049*
R Foraminal Height		0.373	0.400	0.027	−0.003	0.057	0.075

*$P < 0.05$ considered significant; CI = confidence interval; Difference = contrast between parallel and perpendicular measurements; †Right dorsal to left ventral height; ‡Left dorsal to right ventral height.

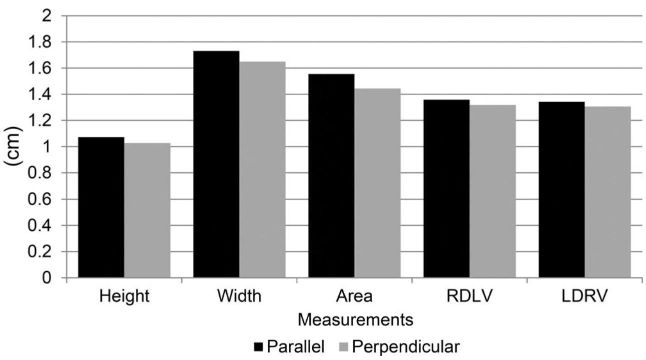

FIG. 4. Differences in height, width, area, RDLV, and LDRV at the cranial aspect of the cervical vertebrae in affected and control Great Danes as a result of angle acquisition.

of affected and control dogs were consistently larger when acquired parallel to the endplate, as shown in Fig. 4. The measurements at the middle and caudal locations did not vary significantly based on angle acquisition. Also, for the combined population, only the left intervertebral foraminal height measurements varied significantly when measured on the transverse images acquired in the different angle planes ($P = 0.049$, Table 4). The right intervertebral foraminal height measurements did not show significant differences between those measured on the images acquired parallel to the endplate versus those images acquired perpendicular to the vertebral canal ($P = 0.075$).

Table 5 summarizes the results of the random-effects linear regression model comparing the measurements from the control and affected groups for each angle of acquisition. The vertebral foraminal width was significantly smaller in affected dogs when compared to control dogs regardless of the angle of acquisition ($P = 0.039$ when acquired parallel to the endplates and $P = 0.012$ when acquired perpendicular to the vertebral canal). Similarly, right and left intervertebral foraminal height measurements obtained from affected dogs were significantly smaller than those obtained from control dogs ($P < 0.001$) for both types of angle acquisition. Lastly, the calculated rho (ρ) values demonstrated excellent intraobserver agreement for height ($\rho = 0.974$), width ($\rho = 0.995$), area ($\rho = 0.989$), RDLV ($\rho = 0.987$), LDRV ($\rho = 0.992$), left intervertebral foraminal height ($\rho = 0.975$), and right intervertebral foraminal height ($\rho = 0.962$).

Discussion

The purpose of our study was to determine if angle acquisition during CT scanning significantly affects cervical vertebral column morphometry. Our results showed that vertebral foraminal measurements acquired at the two different angles varied significantly only at the cranial aspect of the cervical vertebrae. Vertebral foraminal height, width, area, RDLV, and LDRV measurements all showed significant differences when obtained from the cranial vertebral locations on the transverse images acquired parallel to the endplates versus those obtained from the transverse images acquired perpendicular to the vertebral canal. None of the vertebral foraminal measurements, however, revealed significant variances between the different angles of acquisition at the middle or caudal locations of the vertebrae. The differences in height, area, RDLV, and LDRV at the cranial vertebral locations may be explained by the existence of vertebral foraminal stenosis described in dog breeds predisposed to cervical spondylomyelopathy.[2,5–7,18] The cervical vertebral foramina of large breed dogs has a funnel-shaped appearance when compared to small breed

TABLE 5. Comparison of Cervical Vertebral Column Morphometry between Control Great Danes and Great Danes with Cervical Spondylomyelopathy for each Type of Angle Slice Acquisition

Variable	Acquisition Angle	Mean Value Affected (cm)	Mean Value Control (cm)	Contrast (Affected vs. Control)	95% Confidence Interval		P-value
Height	Parallel	1.190	1.160	0.030	−0.037	0.097	0.533
	Perpendicular	1.172	1.155	0.017	−0.050	0.085	0.813
Width	Parallel	1.529	1.607	−0.078	−0.153	−0.003	0.039*
	Perpendicular	1.500	1.594	−0.094	−0.169	−0.019	0.012*
Area	Parallel	1.638	1.692	−0.054	−0.187	0.079	0.598
	Perpendicular	1.599	1.682	−0.083	−0.217	0.050	0.299
RDLV†	Parallel	1.464	1.480	−0.016	−0.084	0.052	0.843
	Perpendicular	1.450	1.477	−0.027	−0.096	0.041	0.604
LDRV‡	Parallel	1.446	1.478	−0.033	−0.097	0.032	0.446
	Perpendicular	1.431	1.476	−0.045	−0.110	0.020	0.226
L Foraminal Height	Parallel	0.301	0.482	−0.182	−0.270	−0.094	<0.001*
	Perpendicular	0.331	0.509	−0.178	−0.267	−0.089	<0.001*
R Foraminal Height	Parallel	0.284	0.480	−0.196	−0.282	−0.110	<0.001*
	Perpendicular	0.311	0.507	−0.196	−0.283	−0.109	<0.001*

*$P < 0.05$ considered significant; †Right dorsal to left ventral height; ‡Left dorsal to right ventral height.

dogs due to a dorsoventral narrowing of the cranial aspect of the vertebral foramen, which predisposes them to cervical spinal cord compression.[19] Of the large breed dogs investigated, Great Dane dogs showed the most pronounced stenosis of the cranial aspect of their cervical vertebral foramina.[19] Dorsoventral narrowing may, therefore, be responsible for the significant differences in height, area, RDLV, and LDRV witnessed at the cranial aspect of the vertebrae. Because the vertebral foramina widen in the middle and caudal aspects of the cervical vertebrae in large breed dogs, it is understandable that the measurements obtained at these levels did not show significant differences as we moved further caudally within each cervical vertebra evaluated.

In an osteological study, the cervical vertebrae of Great Danes were shown to bilaterally narrow caudally.[19] However, our results indicated that the vertebral foraminal width varied significantly based on angle acquisition at only the cranial vertebral locations. In general, Great Danes with cervical spondylomyelopathy most often suffer from bilateral compressions in the lateral or dorsolateral direction.[4,5,12,17] In the population of Great Danes enrolled in this study, the lateral compressions more greatly affected the cranial aspect of the vertebrae,[6] explaining why our results differed from the results obtained from osteological studies of the cervical vertebrae of Great Danes.[19] It is also possible that the magnitude of the caudal narrowing of the vertebral foramina is not as pronounced as that of the cranial narrowing, which may have added a degree of difficulty to the identification of statistically significant differences.

As described in human studies,[13] our results showed that obtaining oblique slices through the vertebral canal by orienting the transverse images parallel to the endplates results in larger vertebral canal measurements. Where significant differences were identified, all vertebral foraminal measurements including height, width, area, LDRV, and RDLV, were consistently larger when obtained from images acquired parallel to the endplates. In people, a study showed that lumbar lordosis caused the cross-sectional vertebral canal area to appear larger due to the angulation of the transverse slices.[14]

Regarding the intervertebral foraminal heights, significant differences were only obtained on the left side. In order to evaluate the reliability and repeatability of the measurements investigated in this study, the intraobserver agreement was calculated. Both right and left intervertebral foraminal height measurements were highly repeatable. Therefore, it is most likely that the population of dogs enrolled in this study was affected by more left-sided lesions, and therefore, had more stenotic left intervertebral foramina when compared to the right side. This is further supported by the fact that these significant differences were only maintained in the group of affected dogs when evaluated separately from the control dogs. It is also important to consider that the left foraminal height differences were marginally significant ($P = 0.049$); it is possible that significant differences in right foraminal height may also have been observed if a larger sample size had been evaluated.

Significant morphometric differences were revealed when comparing the two groups of Great Danes, control and affected, regardless of the angle at which the images were acquired. The intervertebral foramina of the affected Great Danes were found to be significantly more stenotic than those of the control group. The differences in intervertebral foraminal height are consistent with the findings of a recent morphometric MR imaging study in Great Danes,[6] but contradicts the findings of a separate morphometric study in Doberman Pinschers.[1] When comparing clinically normal Doberman Pinschers and Doberman Pinschers with cervical spondylomyelopathy, it was demonstrated that there was no significant difference in the intervertebral foraminal heights between the two groups.[1] The discrepant results between Doberman Pinschers and Great Danes are likely related to the fact that these two breeds are affected by two different forms of cervical spondylomyelopathy with differing pathogeneses, namely disk-associated and osseous associated cervical spondylomyelopathy, respectively.[1,2,4,5,20,21] Disk-associated cervical spondylomyelopathy is more commonly seen in middle-aged Doberman Pinschers, while osseous-associated cervical spondylomyelopathy is often seen in young adult giant Great Danes.[2,4–7,20] The disk-associated form of the disease involves ventral compression of the spinal cord secondary to intervertebral disk protrusion, which can be associated with hypertrophy of the soft tissues such as the ligamentum flavum.[1,2,20,21] On the other hand, the osseous-associated form of the disease is most often caused by bony proliferation and remodeling of the articular facets, pedicles, and lamina causing lateral and dorsolateral compressions.[2,4–6] It would seem that bony proliferation of the articular facets and pedicles would be much more likely to consistently cause intervertebral foraminal stenosis than would a ventrally bulging intervertebral disk. Differences in the pathogenesis of the vertebral column abnormalities that cause intervertebral foramina stenosis between disk-associated and osseous-associated cervical spondylomyelopathy likely explain why affected Great Danes have significantly more foraminal stenosis than an equivalent affected group of Doberman Pinschers.

Our results also showed that the width of the vertebral foramina in Great Danes with cervical spondylomyelopathy was significantly narrower than that of the control dogs, regardless of the angle of image acquisition. Considering that Great Danes with cervical spondylomyelopathy most often suffer from lateral or dorsolateral compressions, it is not surprising to find that the CT measurements of affected dogs obtained in this study also showed that their vertebral foramina are laterally narrowed when compared to the control group.[4,5,12,16,17]

In conclusion, findings from the current study indicated that CT slice angle significantly affects cervical vertebral column measurements in Great Danes. Authors recommend that a standardized protocol be adopted for assigning CT slice angles in research studies on canine cervical spinal morphometry and clinical longitudinal studies assessing treatment responses.

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