

# Agreement and Repeatability of Linear Vertebral Body and Canal Measurements Using Computed Tomography (CT) and Low Field Magnetic Resonance Imaging (MRI)

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**Objective**—To evaluate agreement and repeatability of vertebral column measurements using computed tomography (CT) and magnetic resonance imaging (MRI).

**Study Design**—Retrospective observational study.

**Animals**—Dogs (n = 18) with disc associated wobbler syndrome; Dog cadavers (n = 3).

**Methods**—Five measurements of the 5th cervical vertebra were performed: vertebral body length (VBL), vertebral canal height (VCH), vertebral body height (VBH), vertebral canal width (VCW), and vertebral body width (VBW). Measurements were performed independently twice by 2 observers. Bland-Altman plots were created to evaluate agreement. Cadaveric vertebrae with soft tissue removed had the same variables and actual dimensions measured.

**Results**—The largest discrepancy between CT and MRI measurement was for VBL (mean difference  $\pm$  SD = 1.262 mm  $\pm$  1.245;  $P < .001$ ), with the difference for all the other variables being acceptable. The 1st measurement was significantly higher than the 2nd only for VBL using CT (mean difference = 0.476 mm  $\pm$  1.120;  $P = .009$ ), with all other variables having acceptable differences. Mean difference for all measurements between 2 observers was small, except for VBL using CT (mean difference = 0.762 mm  $\pm$  1.042;  $P < .001$ ). Only the difference for VBL between CT and cadaver specimens was statistically significant.

**Conclusions**—Our results suggest high repeatability and good agreement for most vertebral measurements of interest. VBL measurement using CT was considered problematic.

**Clinical Relevance**—Provided limitations are understood, linear measurements of vertebral dimensions from CT and MRI images can be used clinically.

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## INTRODUCTION

DISORDERS OF the vertebral column and spinal cord can be diagnosed by conventional radiography, myelography, computed tomography (CT) or magnetic resonance imaging (MRI) or a combination of techniques.<sup>1</sup> CT and MRI are increasingly used for the diagnosis of neurologic disorders and have largely re-

placed the use of more invasive techniques like myelography. These advanced medical imaging modalities have increased sensitivity, provide accurate anatomic detail, and generate cross sectional images that can be reconstructed in different planes. It is generally accepted that CT gives excellent bone detail whereas MRI is superior to evaluate soft tissue structures including bone marrow.<sup>2–4</sup>

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CT and MRI images have been used for morphometric linear and angular measurements of the vertebral column and spinal cord in different anatomic planes.<sup>5-9</sup> Study results provide information about the pathogenesis, diagnosis, clinical decision-making, presurgical planning, and prognosis of different disorders affecting the vertebral column and spinal cord; however, little is known about the intra—and interobserver agreement of measurements using different imaging modalities or agreement between CT and MRI derived measurements.

Our purpose was to evaluate intraobserver and interobserver agreement, and agreement between measurements made on CT and MRI images of the 5th cervical vertebra (C5) and vertebral canal region.

## MATERIALS AND METHODS

MR and CT images of 18 dogs with disc associated wobbler syndrome (DAWS) were analyzed retrospectively. These dogs were originally enrolled in a study related to diagnosis and treatment of DAWS. Owner consent was obtained before study entry. Complete blood count (CBC) and serum biochemical profile were obtained for all dogs. Echocardiographic examination and standard mucosal bleeding times were performed in most dogs. To compare measurements derived from images with actual dimensions, cadavers of 3 dogs euthanatized for unrelated reasons had the same imaging protocol and then dimensions of the variables of interest were measured using vernier calipers.

### *CT Examination*

Anesthetized dogs (n = 18) and dog cadavers (3) were positioned in dorsal recumbency with the head and neck extended and thoracic limbs fixed parallel to the chest wall. Contiguous slices were made from the mid 4th cervical vertebra (C4) to the mid 7th cervical vertebra (C7), parallel to the intervertebral disk spaces. A single row detector spiral CT (Prospect, GE Medical Systems, Milwaukee, WI) was used with a tube voltage of 100 kVp and 100 mAs. Slice thickness was 3 mm and a bone algorithm was used. 2D multiplanar reconstructed images were made in the sagittal plane.

### *MRI Examination*

MRI examination was performed 1 day after CT examination with the dogs positioned identically. T1 and T2 weighted sequences were performed in the sagittal, dorsal, and transverse planes. Transverse images were aligned perpendicular to the cervical spine. Images were acquired from the 2nd (C2) to the 7th (C7) cervical vertebra in the sagittal and dorsal plane and from C4 to C7 in the transverse plane by a permanent, 0.2T, MRI magnet (Airis Mate, Hitachi, Japan). The cervical spine was positioned in a joint coil with an inner diameter of 19 cm. T1 and T2 weighted images (WI) were obtained using a spin echo technique. Repetition time (TR) and time to echo (TE) of the sagittal T1 WI were TR = 700 ms and TE = 25 ms.

In the sagittal T2 weighted study, TR was 2700 ms and TE = 125 ms. Transverse T1 WI were performed with TR = 1100 ms and TE = 25 ms, and in the T2 weighted transverse images the settings were TR = 5000 ms and TE = 120 ms. Settings used for dorsal images were for T1 weighted: TR = 600 ms; TE = 25 ms and for T2 weighted: TR = 3900 ms; TE = 120 ms. Slice thickness ranged from 2.5–4 mm in the sagittal and dorsal images and was 3 mm in the transverse sequences with no interslice gap.

### *Measurements (Fig 1)*

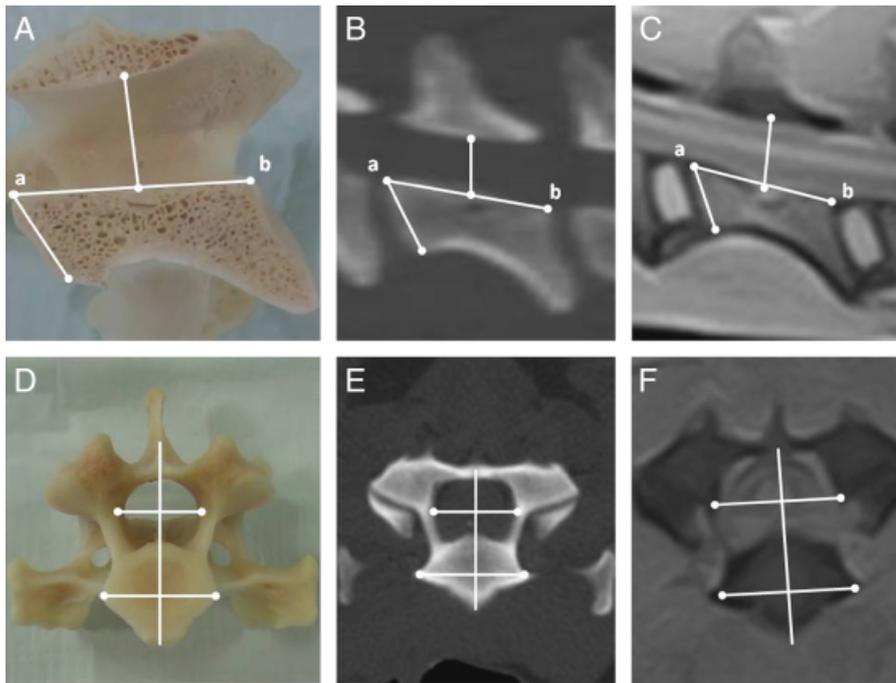
All measurements were made at C5. This region was selected because it was routinely included in the scanning field and has minimal risk of pathologic findings that could interfere with the measurements (ie, vertebral body abnormalities, excessive new bone formation); such pathologic findings were considered an exclusion criteria. The DICOM (Digital Imaging and Communications in Medicine) studies were retrieved and analyzed on eFilm Workstation PACS software (Merge efilm, Merge eMed, Milwaukee, WI) with accuracy limited to 1 mm. In each dog, 5 measurements were made: vertebral body length (VBL), vertebral canal height (VCH), vertebral body height (VBH), vertebral canal width (VCW), and vertebral body width (VBW). VBL, VCH, and VBH were assessed at mid-sagittal T1 WI and at the mid-sagittal reconstructed CT images. VCW and VBW were assessed on transverse T1 W MR images and transverse CT images at the level of the caudal endplate of C5. Each observer (SDD, IG) made measurements twice and independently, with a 2 week separation between each measurement to minimize bias. Each evaluator had an interactive teaching session on methodology and was provided with written instructions. Because of possible variations in magnification, survey radiographs of the cervical spines were not included.<sup>10</sup>

### *Cadaver Measurements*

After imaging the cervical spinal column of 3 canine cadavers, the soft tissue was removed to facilitate measurement of vertebral dimensions. VCW and VBW were measured at the level of the caudal endplate of C5, then the vertebral body was sectioned sagittally and VBL, VCH, and VBH were measured (Fig 1) once by investigator SDD using vernier calipers with an accuracy of 0.01 mm.

### *Data Analysis*

Statistical analysis for VCW, VBW, VBL, VCH, and VBH was based on the paired t-test. First, CT was compared with MRI using a paired t-test with dog-observer-measurement sequence combinations as block factor. Second, the 1st measurement of each observer was compared with the 2nd measurement of each observer (intra-observer agreement) for CT and MRI separately using a paired t-test with dog-observer combinations as block factor. Third, the 1st observer was compared with the 2nd observer (inter-observer agreement) for CT and MRI separately using a paired t-test with



**Fig 1.** Points of measurement illustrated on a cadaveric specimen (A, D), computed tomography (B, E), and magnetic resonance imaging (C, F) images of the same cadaver. A, B, C) Vertebral body length (VBL) was measured from the most craniodorsal point (a) to the most caudodorsal point (B) of the vertebral body. Vertebral canal height (VCH) was measured from the point that corresponded with half of the distance a-b to the shortest distance to the lamina. Vertebral body height (VBH) was measured from (a) to the most cranioventral point of the cranial endplate. D, E, F) Vertebral canal and body width (VCW and VBW) were assessed at their respective broadest points and were measured perpendicular to a reference line that connected the center of the spinal process and the center of the ventral process.

dog-measurement sequence combinations as block factor. Finally, CT and MRI were compared with the true value (based on cadaver measurements) by paired t-test with dog as block factor.

Evaluation of the variability next to difference was based on the Bland-Altman plot which compares 2 measurement sets with difference between measurements on the Y axis and the average of the 2 measurements on the X axis. If 1 method is higher sometimes and method 2 is higher at other times, the mean differences will be close to zero. If the mean difference is not close to zero, this indicates that the 2 measurement methods are producing different results. Using Bland-Altman plots, the mean difference between the 2 techniques, between the 2 observers and between the 2 measurements of the same observer, its standard deviation (SD), and the lower and upper limit of agreement (mean  $\pm$  SD) are given (Figs 2 and 3).

## RESULTS

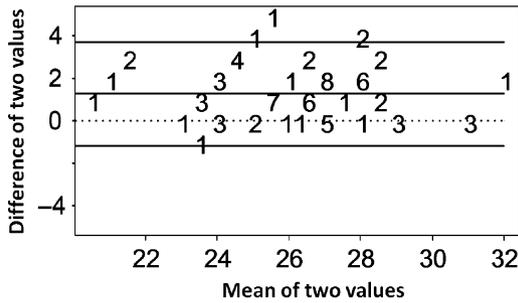
### Dogs

Of 18 dogs, 12 were Doberman Pinschers with 2 Dalmatian, 2 Whippet, 1 Weimaraner, and 1 Bernese mountain dog; 7 dogs were male and 11 were female. Median age was 7.9 years (range, 4.6 years –12.8 years) and median weight was 32.2 kg (range, 11–44.6 kg). No abnor-

malities were detected on physical examination, CBC, serum biochemical profile, standard mucosal bleeding time, and echocardiographic examination. Dog cadavers were a 2-year-old female Labrador retriever, a 7-year-old male crossbreed, and an 18 month old male Bordeaux Dog.

### Agreement between MRI and CT Measurements

CT leads to significantly higher values than MRI for VBL (mean difference  $\pm$  SD = 1.260 mm  $\pm$  1.250;  $P < .001$ ) and for VBW (mean difference = 0.238 mm  $\pm$  0.701;  $P = .0027$ ), whereas CT leads to significantly lower values than MRI for VCW (mean difference = -0.131 mm  $\pm$  0.530;  $P = .0269$ ). CT did not differ significantly from MRI for VCH (mean difference = 0.048 mm  $\pm$  0.489;  $P = .374$ ) and VBH (mean difference = -0.059 mm  $\pm$  0.585;  $P = .356$ ). Bland-Altman plots indicate low variability of the difference between CT and MRI for VCH, VBH, and VCW, a somewhat higher variability for VBW, and an unacceptably high variability for VBL (Fig 2). The resulting limits of agreement (LOA) were considered clinically acceptable for all measurements except for VBL (upper LOA: 3.70 mm).



**Fig 2.** Bland-Altman plot for the measurement sets for vertebral body length (VBL) between CT and MRI. The X-axis shows the mean of the 2 values, whereas the Y-axis shows the difference between the 2 values. The numbers on the figure represent how many times a specific combination occurred. The horizontal lines on the figure correspond with the mean difference of the 2 values (middle horizontal line) and the 95% limits of agreement (upper and lower horizontal line). The dotted horizontal line corresponds with a zero mean difference for the measurements.

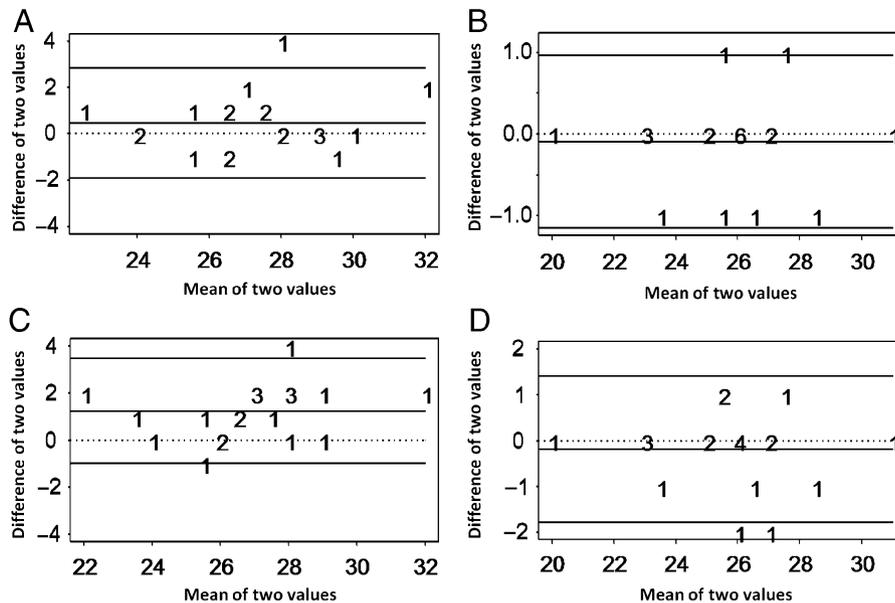
*Intraobserver Agreement*

For both observers, the 1st measurement was significantly higher than the 2nd measurement only for VBL using CT (mean difference = 0.476 mm ± 1.120; P =

.0093). The mean difference between 1st and 2nd measurements for the other variables was always small, regardless the used technique (Table 1). The Bland-Altman plots indicate very low variability between the intraobserver difference of the 1st and 2nd measurement, except for VBL using CT for both observer (Fig 3A and B) and a somewhat higher variability for VBW using CT for 1 of the observers. The resulting LOA were considered clinically acceptable, with the exception of the upper LOA for VBL using CT (2.67 mm).

*Interobserver Agreement*

There was a significant difference between all measurements for both observers, except for VBL using MRI (Table 1). Mean difference for all measurements between the 2 observers was close to zero, with the highest value for VBL using CT (mean difference = 0.762 mm ± 1.042; P < .001) (Fig 3C and D). The Bland-Altman plots indicate low variability for VBL, VCH, and VBH using MRI and VCH, VBH, and VCW using CT and a somewhat higher variability for the other measurements. The resulting LOA were considered clinically acceptable, with the exception of the upper LOA for VBL using CT (2.80 mm) and the lower LOA for VBW using CT and MRI (-1.87 mm and -2.17 mm, respectively).



**Fig 3.** Bland-Altman plots for the measurement sets for vertebral body length (VBL) using CT and MRI between different observers and different times. The measurement sets for 1 observer at different times using CT and MRI is represented by (A) and (B), respectively. Measurement sets between different observers using CT and MRI is represented by (C) and (D), respectively. The X-axis shows the mean of the 2 values whereas the Y-axis shows the difference between the 2 values. Numbers on the figure represent how many times a specific combination occurred. The horizontal lines on the figure correspond with the mean difference of the 2 values (middle horizontal line) and the 95% limits of agreement (upper and lower horizontal line). The dotted horizontal line corresponds with a zero mean difference for the measurements. Overall, a higher mean difference and variability using CT (A) and (C) can be noticed when compared with MRI (B) and (D).

Table 1. Mean Differences, *P*-Values, Standard Deviations and Associated Limits of Agreement (LOA) for the Different Measured Variables

Assessed Variable	Mean Difference (mm)	<i>P</i> Value	SD (mm)	Lower LOA (mm)	Upper LOA (mm)
<b>CT-MRI</b>					
VBL	1.262	<0.001	± 1.245	-1.179	3.702
VCH	0.0482	0.374	± 0.489	-0.909	1.006
VBH	-0.0595	0.356	± 0.585	-1.205	1.086
VCW	-0.131	0.0269	± 0.530	-1.169	0.907
VBW	0.238	0.0027	± 0.701	-1.135	1.611
<b>Intraobserver (M1-M2)</b>					
VBL CT	0.476	0.0093	± 1.118	-1.715	2.667
VBL MRI	-0.143	0.0832	± 0.515	-1.152	0.867
VCH CT	-0.0238	0.710	± 0.408	-0.823	0.775
VCH MRI	0.0732	0.262	± 0.407	-0.724	0.870
VBH CT	0.167	0.0510	± 0.531	-0.874	1.207
VBH MRI	0.0952	0.323	± 0.610	-1.100	1.290
VCW CT	-0.0952	0.290	± 0.569	-1.211	1.021
VCW MRI	-0.0238	0.743	± 0.462	-0.930	0.882
VBW CT	0.214	0.0596	± 0.708	-1.174	1.603
VBW MRI	0.0714	0.538	± 0.737	-1.372	1.515
<b>Interobserver (obs1-obs2)</b>					
VBL CT	0.762	<0.001	± 1.042	-1.281	2.805
VBL MRI	-0.0476	0.570	± 0.532	-1.091	0.996
VCH CT	0.167	0.0331	± 0.484	-0.782	1.115
VCH MRI	0.195	0.0190	± 0.505	-0.794	1.184
VBH CT	0.262	0.0099	± 0.620	-0.952	1.476
VBH MRI	0.238	0.0235	± 0.648	-1.031	1.508
VCW CT	0.286	0.0058	± 0.628	-0.945	1.517
VCW MRI	0.0405	<0.001	± 0.491	-0.557	1.367
VBW CT	-0.262	0.0468	± 0.818	-1.866	1.342
VBW MRI	-0.405	0.0064	± 0.901	-2.171	1.362

VBL = vertebral body length; VCH = vertebral canal height; VBH = vertebral body height; VCW = vertebral canal width; VBW = vertebral body width; M1 = first measurement; M2 = second measurement; obs1 = observer 1; obs2 = observer 2.

### Cadaver Measurements

CT leads to significantly higher values than the actual dimension from the cadaveric vertebrae for VBL (mean difference = 2.220 mm ± 0.169; *P* = .00583). Mean differences between other measurements were lower and did not reach statistical significance.

## DISCUSSION

We are unaware of other in vivo studies in dogs comparing intra—and interobserver agreement of linear vertebral body and canal measurements using CT and MRI.

### Agreement between CT and MRI Measurements

There was good agreement between most vertebral measurements using CT and MRI in dogs, similar to a report in people<sup>10</sup>; however, poor and clinically unacceptable agreement was observed for VBL. This was caused by a highly significant and consistently higher value for this variable using CT. Results from cadaveric vertebrae confirmed this finding and indicated a consistent and clinically important overestimation of VBL us-

ing CT compared with MRI. This important finding is in agreement with studies in people and using phantoms,<sup>11,12</sup> where there were larger values for measurements in the reconstructed craniocaudal or *z*-axis, dependent on the selected reconstruction parameters.<sup>12</sup> This overestimation occurred mainly in images with limited spatial resolution in the craniocaudal plane of the reconstructed CT images.<sup>11,13</sup> Spatial resolution of most CT scanners is less in the reconstructed sagittal plane than in the transverse (image) plane,<sup>14</sup> largely because of the partial volume effect.<sup>11,13,14</sup> The partial volume effect is explained by the fact that a CT image represents a certain slice thickness: when 2 different densities are present in a single slice, the average density is displayed in the image. This occurs where only an edge of a structure is included in the slice and results in averaging of the tissues.<sup>15</sup> Smaller slice thickness and overlap between slices decreases the effects of partial volume averaging.<sup>11,13,15</sup> This effect is illustrated in a recent study where reconstructed CT images were used for assessment of joint spaces in the canine elbow.<sup>16</sup> There was good agreement between reconstructed CT images and cadaveric specimens; however, slice thickness was 1.2 mm with an overlap of 0.2 mm between the slices. Disadvantages of

such a detailed CT-imaging protocol are the prolonged scanning times and increased patient radiation exposure.<sup>13</sup>

There is uncertainty about the usefulness of MRI to assess cortical bone.<sup>2</sup> Our results suggest that accurate bony measurements can also be made with MRI. Further, use of devices with higher magnetic fields than the 0.2T we used would yield more anatomic detail and less variability in measurements.<sup>17</sup>

#### *Intra-and Interobserver Agreement*

Our data indicate that except for isolated variables, linear measurements from transverse and sagittal CT and MRI images of the vertebral body and canal have high repeatability. The observed mean differences were small and largely accounted for by limitations in precision of the calibrated ruler. In agreement with others studies, intraobserver agreement was considerably higher than interobserver agreement.<sup>18,19</sup> This conclusion was based on lower mean differences, lower standard deviations, and lower variability evident in respective Bland-Altman plots for intraobserver agreement when compared with interobserver agreement. The relative lower intra—and interobserver agreement for VBL and lower interobserver agreement for VBH using CT when compared with MRI is likely caused by the reconstruction of these images. Sagittal reconstruction of the axial CT images can cause imprecise resolution of the bone contour leading to loss of detail and a degree of subjectivity in accurately measuring certain variables.<sup>16</sup> Like CT, MRI provides cross-sectional images but, unlike CT, these can be directly obtained in any plane without the need for computer assisted reconstruction and subsequent detail loss.<sup>2</sup> The relatively lower interobserver agreement for VBW using CT and MRI is likely caused by the irregular margins normally seen in the endplates of each vertebra. This may have affected the location of the lines traced for measurement of VBW.

#### *Interpretation and Study Limitations*

Measurements made from CT and MRI images are only useful if they have low variability, even if on average the difference is zero (no bias). On the other hand, even if measurements differ significantly from each other, but the largest part of the differences falls in an interval that is clinically acceptable, the technique is still acceptable.

It is most unlikely that measurements within and between observers, and made using different imaging modalities will agree exactly yielding identical results for all measurements, so we assessed agreement using Bland-Altman plots. The information regarding clinical significance must be interpreted with care because a significant

difference does not indicate a clinically important difference or a lack of agreement between both measurement sets. Statistical significance only indicates that the mean difference is caused by a consistently higher or lower value for 1 of the 2 measurement sets. The most important and clear example in our study is the highly statistically ( $P < .001$ ) greater value for VBL using CT compared with MRI. Because the mean difference, variability, and associated LOA were very high, this difference was considered important and clinically unacceptable. How far apart measurements can be without causing difficulties will be a question of judgment—a clinical question, not a statistical one. This decision will vary for different clinical applications. We considered a mean difference  $> 1$  mm (accuracy of the measurement tool) and LOA that approached  $\pm 2$  mm as clinically important. Such values can and probably will differ for different clinical objectives.

Our results are limited by the retrospective nature of the study and by the fact that the effects of different image analysis software packages were not investigated. Certain variables, like VCH and VBH are probably easier and more accurately assessed on transverse images. These measurements were not performed on the transverse images because of differences in the orientation of the transverse slices between CT and MRI images. It is possible that more precise measurement tools (1 mm in this study) would have affected the observed differences and this could be of particular interest in assessment of rather small anatomic measurements, like VCH, VBH and VBW. This in part supported by the excellent intra- and interobserver agreement for MRI measurement of VBL (Fig 3B and D) because this measurement generally accounted for the largest distance of all assessed variables.

Our results suggest high repeatability and good agreement for most cervical vertebral measurements using CT and MRI. Further, we demonstrated the limitations of linear measurements in sagittal reconstructed CT images, particularly in the craniocaudal plane. Evidence from human and phantom studies suggests that this unreliability can be improved by altering the operator settings of the CT scanner<sup>11,12,15</sup>; however this has not been investigated in dogs. Recognizing the usefulness and limitations of CT and MRI image measurements can be of considerable importance in clinical decision-making and presurgical planning for various disorders of the vertebral column and spinal cord.

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