Radiographic assessment of the cardiac silhouette in clinically normal large- and small-breed dogs

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OBJECTIVE

To determine manubrium heart scores (MHSs) from measurements of cardiac short-axis length (cSAL) and long-axis length (cLAL) relative to the corresponding manubrium length (ML) on thoracic radiographic views of dogs and assess correlation of MHSs with vertebral heart scores (VHSs).

ANIMALS

120 clinically normal large-breed dogs (LBDs) and small-breed dogs (SBDs).

PROCEDURES

On right lateral views (RLVs) and ventrodorsal views (VDVs) for each dog, cSAL and cLAL were measured and expressed as a ratio; the cSAL:ML ratio (short-MHS), cLAL:ML ratio (long-MHS), and cSAL-and-cLAL:ML ratio (overall-MHS) were also calculated. The VHS was determined from the RLV. Correlation of VHS with MHS was assessed.

RESULTS

On RLVs and VDVs, mean cSAL:cLAL ratios were 0.77 (SD, 0.05) and 0.72 (SD, 0.05), respectively, in 60 LBDs and 0.81 (SD, 0.06) and 0.78 (SD, 0.06), respectively, in 60 SBDs. In LBDs, mean short-MHS, long-MHS, and overall-MHS were 2.1 (SD, 0.22), 2.7 (SD, 0.24), and 4.8 (SD, 0.5), respectively, on RLVs and 2.3 (SD, 0.26), 3.2 (SD, 0.34), and 5.4 (SD, 0.6), respectively, on VDVs. In SBDs, mean short-MHS, long-MHS, and overall-MHS were 2.4 (SD, 0.39), 2.9 (SD, 0.50), and 5.3 (SD, 0.83), respectively, on RLVs and 2.5 (SD, 0.44), 3.2 (SD, 0.51), and 5.8 (SD, 0.92), respectively, on VDVs. Mean VHSs were 10.73 (SD, 0.52) and 10.27 (SD, 0.81) in LBDs and SBDs, respectively. A significant correlation was identified between VHS and each MHS in LBDs.

CONCLUSIONS AND CLINICAL RELEVANCE

In the dogs evaluated, radiographic cardiac dimensions and MHSs were correlated. Validity of the MHS for cardiac dimension assessment in other healthy dogs and dogs with cardiac disease warrants investigation. (Am J Vet Res 2017;78:168–177)

Radiographic assessment of cardiac dimensions may reveal an altered anatomic structure secondary to eccentric cardiac enlargement. Radiography is fairly reliable for evaluation of generalized cardiomegaly or pericardial effusion and some types of chamber enlargement such as left atrial enlargement and, to a lesser extent, right atrial and ventricular enlargements. Radiographic assessment of the cardiac dimensions may be important for initial evaluation of heart disease and could be a reliable index of pathological changes associated with the heart. However, echocardiography remains the gold standard for anatomic evaluation of the internal cardiac structures when a cardiac abnormality is suspected on the basis of clinical or historical information or an altered radiographic appearance of the cardiac silhouette.

Cardiac size has been previously evaluated mathematically on the basis of the dimensions of other structures on thoracic radiographic views. A simple quantitative technique of cardiac measurement—the VHS—has been widely used to evaluate the size of the cardiac silhouette with respect to the length of the corresponding midthoracic vertebrae starting at T4 in both dogs and cats. However, potential sources of VHS variation included interobserver differences in the selection of reference points and transformation of cSAL and cLAL into VHS units. Additionally, thoracic vertebral anomalies such as butterfly vertebrae and hemivertebrae in brachycephalic-breed dogs and thoracic intervertebral disk disease increase the inci-
dence of erroneously high assessments of VHS. Short thoracic vertebrae in some breeds, such as Labrador Retriever, Boxer, Cocker Spaniel, Bulldog, and Boston Terrier, may also result in a higher VHS and subsequent false-positive radiographic diagnosis of cardiomegaly in these dog breeds.

Other radiographic techniques have relied on determination of the cardiothoracic ratios derived from lateral thoracic radiographs obtained after peak inspiration and expiration. Additionally, other studies have used these same techniques on both lateral and ventrodorsal radiographs after peak inspiration and expiration. These techniques were reported to be complicated and not suitable for clinical practice because they require a specific software program and were not effective in dogs with certain cardiovascular or pulmonary abnormalities. In addition, the marked variation in thoracic cavity conformation among dog breeds makes cardiothoracic ratios of little value. Even in the same individual, standard ratios are unreliable for assessment of sequential changes in cardiac size. All previously reported techniques (determination of VHS or cardiothoracic ratios) relied on evaluation of the overall size of the cardiac silhouette without separate assessment of each cardiac axis (cSAL and cLAL) on lateral and ventrodorsal thoracic radiographs. Alternatively, the use of an MHS eliminates some of the problems associated with the VHS and cardiothoracic ratios in some dogs. The manubrium of the sternum was selected because it is a relatively prominent, regularly elongated, bullet-shaped cranioventral bone segment that is easily identified and can be readily measured on lateral thoracic radiographic views.

Therefore, the objective of the study reported here was to determine MHSs from measurements of cSAL and cLAL normalized by the ML on right lateral and ventrodorsal thoracic radiographic views of clinically normal dogs. The cSAL:cLAL ratio was also calculated from measurements obtained on both radiographic views. After 3 MHSs were calculated on the basis of the cSAL:ML ratio, cLAL:ML ratio, and cSAL and cLAL:ML ratio from both radiographic views, the correlation of each of those scores with the VHS (derived from the right lateral radiographic view) was assessed. Our first hypothesis was that ML would be an appropriate reference measurement with which to assess cardiac size in a study population of 120 healthy small- and large-breed dogs. Our second hypothesis was that the VHS would be correlated with each of the 3 MHSs determined for the same population of dogs.

Materials and Methods

Dogs

Medical records and thoracic radiographs of large-breed (≥ 16 kg) and small-breed (≤ 12 kg) dogs admitted to the Small Animal Hospital at the University of Florida College of Veterinary Medicine were retrospectively retrieved between February and November 2014. Data used in the study related to client-owned dogs, all of which were ≥ 1.5 years old, had no history or clinical signs of cardiovascular disorders (no record of a heart murmur or gallop detected during thoracic auscultation) or respiratory tract diseases, and had no detectable abnormalities on thoracic radiographs (3 radiographic views [right lateral, left lateral, and ventrodorsal images]). A corresponding echocardiogram was not required for the dogs to be included in the study. An additional inclusion criterion was that dogs had right lateral and ventrodorsal thoracic radiographic views that had been obtained at the time of peak inspiration, as previously reported, and without the use of sedation or an anesthetic agent. According to a previous study, dogs with a VHS value < 10.9 were categorized as clinically normal and included in this study. Dogs with obvious radiographic evidence of vertebral anomalies such as hemivertebrae or abnormally shaped thoracic vertebrae were excluded from this study. In addition, when dogs had radiographic views on which the manubrium appeared abnormally shaped or its cranial margin could not be identified, they were excluded from the study. The length of evenly elongated, bullet-shaped (round cranial margin), rectangular (flat cranial margin), or camel head-neck-shaped manubriums was considered to be acceptable for normalization of the cardiac axes measured on both right lateral and ventrodorsal radiographic views (Figure 1).

Radiographic measurements

For each dog, radiographic measurements were performed on right lateral and ventrodorsal thoracic radiographic views obtained with a digital radiography plate. Radiographic procedures were standardized (with standard exposure factors and x-ray-tube distance) and approved in terms of quality and positioning by a board-certified radiologist (CRB). All digitized radiographs were retrieved with an image archiving communication system and a medical workstation. Images were analyzed by the same investigator (AAM) with medical and radiologic image-processing software. On the right lateral view of the thorax, the VHS was determined on the basis of a previously published method that used the dimensions of the long and short axes of the cardiac silhouette to

Figure 1—Representative lateral radiographic views of elongated, bullet-shaped (A and B), rectangular (C), and camel head-neck-shaped (D) canine manubriums that were considered acceptable for measurement of length, which was subsequently used to normalize the cSAL and cLAL (ie, determination of the cSAL:ML ratio [short-MHS], cLAL:ML ratio [long-MHS], and cSAL-and-cLAL:ML ratio [overall-MHS]) obtained from lateral and ventrodorsal thoracic radiographs of dogs.
indicate the number of vertebrae, starting at the cranial endplate of the fourth thoracic vertebra (Figure 2). The cLAL was measured from the ventral border of the carina to the most caudoventral margin of the cardiac apex. The cSAL was measured at the widest point of the cardiac silhouette on a line perpendicular to the long axis. The maximum ML was measured on the right lateral view. On the ventrodorsal view, the long and short axes of the cardiac silhouette were also measured as described. The cLAL was defined as the distance from the right cranial margin of the cardiac silhouette (possibly the right atrium) to the cardiac apex (possibly the left ventricular apex), whereas the cSAL was estimated as the widest line perpendicular to the long axis (Figure 3). To mitigate the differences in cardiac dimensions related to interbreed variation, the cSAL and cLAL measured on both radiographic views were expressed relative to each other and to the corresponding ML. Additionally, the sum of the cSAL and cLAL on each radiographic view was normalized by the corresponding ML. In other words, the cSAL:ML ratio (short-MHS), cLAL:ML ratio (long-MHS), and cSAL-and-cLAL:ML ratio (overall-MHS) were also calculated from both right lateral and ventrodorsal radiographic views for all dogs. Pleural fat opacity was excluded during measurements of the cSAL and cLAL on both views.

On right lateral radiographs, the long axis of the canine heart reflects the combined size of the left atrium and left ventricle; the short axis includes portions of the right and left cardiac chambers and spans the atria, most likely at the level of the coronary groove and atrioventricular valves. On ventrodorsal radiographs, the long axis of the canine heart reflects the combined size of right atrium and left ventricle; the short axis includes the right ventricle and left atricle and possibly the main pulmonary artery.

Statistical analysis
Data were tested for normality with the D’Agostino and Pearson omnibus test before statistical analysis. Data were normally distributed and reported as mean (SD). Variables of interest were compared with an unpaired, 2-tailed t test by use of commercial scientific 2D graphing and statistics software. A 95% CI was calculated for each selected measurement with the same statistical software. A Spearman rank correlation coefficient (r_s) and R^2 value were calculated to evaluate the relationship between VHS measured on right lateral radiographs and each of the MHSs derived from right lateral and ventrodorsal views for each breed group. A Spearman rank correlation co-
efficient \((r_s)\) was also calculated to evaluate the relationship between the VHS and the sum of the cSAL and cLAL measured on each radiographic view for all dogs. In addition, the correlations of ML with cSAL, with cLAL, and with the sum of the cSAL and cLAL measured on each radiographic view were assessed by use of the same statistical test for all dogs. The correlation between ML and body weight of each breed group was also evaluated. For all analyses, a value of \(P < 0.05\) was considered significant.

**Results**

**Dogs**

A total of 120 large- and small-breed dogs (60 dogs/breed group) met the criteria for inclusion in the study reported here. The mean (SD) age was 7.9 years (SD, 3.5 years) in the large-breed group and 9.1 years (SD, 3.7 years) in the small-breed group. The mean body weight was 31.1 kg (SD, 10.6 kg) in the large-breed group and 7.7 kg (SD, 3.7 kg) in the small-breed group. There was no significant difference in mean age between the large- and small-breed dogs; however, a significant \((P < 0.001)\) difference in mean weight between the 2 breed groups was identified. Among the large-breed dogs, there were 28 females (20 of which were neutered) and 32 males (25 of which were neutered); among the small-breed dogs, there were 33 females (27 of which were neutered) and 27 males (24 of which were neutered). Among the 120 dogs, there were 100 purebred dogs (representing 42 breeds) and 20 mixed-breed dogs (Table 1). All dogs were admitted to the hospital for reasons other than cardiovascular or respiratory tract disorders; most commonly, dogs were admitted for routine evaluation for pulmonary metastases, and thoracic radiography revealed no abnormalities. Three small-breed dogs (a Miniature Poodle, a Chihuahua, and a Scottish Terrier) were excluded from the initial small-breed group because they had radiographic evidence of a deformed manubrium. The Miniature Poodle and Chihuahua had a short, faintly visible manubrium, whereas the Scottish Terrier’s manubrium was fused with the second sternebra (Figure 4). An additional 3 small-breed dogs were included in this breed group as replacements. None of the large-breed dogs had radiographic evidence of congenital anomalies of the manubrium.

**Radiographic measurements**

Analyses revealed that there was a significant positive correlation \((r_s = 0.75; P < 0.001)\) between the ML and the body weight for each breed group (same \(r_s\) and \(P\) value). Significant correlations \((r_s \geq 0.93; P < 0.001)\) were identified between the ML and the corresponding cSAL or cLAL measured on the right lateral and ventrodorsal radiographic views. Accordingly, the sum of the cSAL and cLAL obtained from each radiographic view correlated significantly \((r_s \geq 0.94; P < 0.001)\) with the ML (Figure 5). However, weak correlations between VHS

### Table 1—Breed distribution of 120 clinically normal large- and small-breed dogs used in a study to determine MHSs from measurements of cSAL and cLAL relative to the corresponding ML on thoracic radiographic views and assess correlation of MHSs with VHSs.

<table>
<thead>
<tr>
<th>Breed</th>
<th>Large-breed dogs (n = 60)</th>
<th>Small-breed dogs (n = 60)</th>
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<td>No. of dogs (%)</td>
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<td><strong>Large-breed dogs</strong></td>
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<td>Labrador Retriever</td>
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<td><strong>Small-breed dogs</strong></td>
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<td><strong>Mixed-breed dogs</strong></td>
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<td>Cavalier King Charles Spaniel</td>
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and the sum of the cSAL and cLAL obtained from the right lateral ($r_s = 0.36; P < 0.001$) and ventrodorsal ($r_s = 0.33; P < 0.001$) views were identified.

**Large-breed dogs**

For the large-breed group, the cSAL:cLAL ratio derived from the right lateral radiographic view measurements was greater ($P < 0.001$) than that derived from the ventrodorsal view measurements (Table 2). The cSAL was 76% to 78% of the cLAL on the lateral view (95% CI of lateral view cSAL:cLAL ratio) and 71% to 74% of the cLAL on the ventrodorsal view (95% CI of ventrodorsal view cSAL:cLAL ratio). The cSAL and cLAL each normalized by the length of the
manubrium (ie, short-MHS and long-MHS, respectively) were greater (both $P < 0.001$) for the ventrodorsal view, compared with values for the lateral view. The cLAL was 3.1 to 3.3 times the ML on the ventrodorsal view (95% CI of ventrodorsal view cLAL:ML ratio) and 2.7 to 2.8 times the ML on the lateral view (95% CI of lateral view cLAL:ML ratio). The cSAL was 2.2 to 2.3 times the ML on the ventrodorsal view (95% CI of ventrodorsal view cSAL:ML ratio) and 2.0 to 2.2 times the ML on the lateral view (95% CI of lateral view cSAL:ML ratio). The sum of the cSAL and cLAL normalized by the corresponding ML (ie, overall-MHS) was greater ($P < 0.001$) for the ventrodorsal view, compared with the value for the lateral view (Table 1). The 95% CIs of the overall-MHS were 4.7 to 5.0 and 5.3 to 5.6 for the lateral and ventrodorsal radiographic views, respectively. The mean VHS was 10.7 (SD, 0.5) with a 95% CI of 10.6 to 10.9.

Weak correlations between VHS derived from the lateral view and overall-MHS derived from the lateral view ($r_s = 0.42; P < 0.001; R^2 = 0.13$; overall-MHS [lateral] = 0.33•VHS + 1.25 [Figure 6]) and for the ventrodorsal view ($r_s = 0.51; P = 0.02; R^2 = 0.08$; overall-MHS [ventrodorsal] = 0.32•VHS + 2.04) were identified. Also, weak correlations (correlation range, 0.43 to 0.48) were identified between VHS and each of the short- and long-MHS for the lateral and ventrodorsal radiographs. However, there was no correlation between VHS and cSAL:cLAL ratio derived from the lateral or ventrodorsal views.

**Small-breed dogs**

For the small-breed group, the cSAL:cLAL ratio derived from the right lateral radiographic view measurements was greater ($P = 0.04$) than that derived from the ventrodorsal view measurements (Table 2). The cSAL was 80% to 83% of the cLAL on the lateral view (95% CI of lateral view cSAL:cLAL ratio) and 77% to 80% of the cLAL on the ventrodorsal projection (95% CI of the ventrodorsal cSAL:cLAL ratio). The short-MHS and long-MHS were greater ($P = 0.02$ and $P = 0.002$, respectively) for the ventrodorsal view, compared with values for the lateral view. The cSAL was 2.4 to 2.6 times the ML on the ventrodorsal view (95% CI of ventrodorsal view cSAL:ML ratio) and 2.3 to 2.5 times the ML on the lateral view (95% CI of lateral view cSAL:ML ratio). The cLAL was 3.1 to 3.3 times the ML on the ventrodorsal view (95% CI of ventrodorsal view cLAL:ML ratio) and 2.8 to 3.0 times the ML on the lateral view (95% CI of lateral view cLAL:ML ratio). The overall-MHS was greater ($P =

Figure 6—Scatterplot of VHS (number of vertebrae) and the overall-MHS determined from right lateral thoracic radiographic views obtained from 60 clinically normal large-breed dogs.
the clinically normal dogs used in the present study, the VHS may not differ from the corresponding ratio for dogs with generalized cardiomegaly or a pericardial effusion. The cSAL:cLAL ratio, short- and long-MHS, were greater (P < 0.001, P < 0.001, and P = 0.009, respectively) for small-breed dogs, compared with findings for large-breed dogs. The overall-MHS derived from the lateral view was greater (P < 0.001) for small-breed dogs than it was for large-breed dogs. For the ventrodorsal thoracic radiographs, the cSAL:cLAL ratio and short-MHS were greater (both P < 0.001) for small-breed dogs, compared with findings for large-breed dogs. For small-breed dogs, the overall-MHS derived from the ventrodorsal view was greater (P = 0.05) than that for large-breed dogs. However, there was no significant (P = 0.5) difference in the long-MHS derived from the ventrodorsal view between the 2 breed groups. The VHS was greater (P < 0.001) for large-breed dogs than it was for small-breed dogs.

Radiographic measurements for large-versus small-breed dogs

For the right lateral thoracic radiographs, the cSAL:cLAL ratio, short-MHS, and long-MHS were greater (P < 0.001, P < 0.001, and P = 0.009, respectively) for small-breed dogs, compared with findings for large-breed dogs (Table 2). In addition, the overall-MHS derived from the lateral view was greater (P < 0.001) for small-breed dogs than it was for large-breed dogs (Table 2). For the ventrodorsal thoracic radiographs, the cSAL:cLAL ratio and short-MHS were greater (both P < 0.001) for small-breed dogs, compared with findings for large-breed dogs. For small-breed dogs, the overall-MHS derived from the ventrodorsal view was greater (P = 0.05) than that for large-breed dogs. However, there was no significant (P = 0.5) difference in the long-MHS derived from the ventrodorsal view between the 2 breed groups. The VHS was greater (P < 0.001) for large-breed dogs than it was for small-breed dogs.

Discussion

The main findings of the present study in small- and large-breed dogs indicated that cardiac dimensions measured on the right lateral and ventrodorsal radiographic views of the thorax were strongly correlated with the ML and weakly correlated with the VHS. The VHS and each calculated MHS were weakly correlated in large-breed dogs and were not correlated in small-breed dogs. Accordingly, we propose that an increased value of the short-MHS derived from the right lateral or ventrodorsal view (with an apparently normal long-MHS) may reflect left- or right-sided cardiomegaly. On the other hand, an increased value of the long-MHS derived from the right lateral view (with an apparently normal short-MHS) may indicate left atrial or left ventricular enlargement (or both) with an associated elongated appearance of the cardiac silhouette. An increased value of the long-MHS derived from the ventrodorsal view (with an apparently normal short-MHS) may suggest right atrial or left ventricular enlargement (or both) with an associated elongated appearance of the cardiac silhouette. However, the cSAL:cLAL ratio derived from right lateral or ventrodorsal thoracic radiographic views of dogs with generalized cardiomegaly or a pericardial effusion may not differ from the corresponding ratio for the clinically normal dogs used in the present study if both cardiac axes increase proportionally in size in affected dogs. Further studies are required for verification of these proposed interpretations of the MHs.

During the preceding 2 decades, determination of the VHS as an objective method for assessing cardiomegaly in dogs has generated a great deal of interest. However, thoracic vertebral anomalies and short vertebrae associated with certain dog breeds, and the interobserver variation in VHS assessment along with the lack of evaluating VHS on ventrodorsal thoracic radiographs, were the main impetuses for undertaking the present study. In addition, the VHS and published cardiothoracic ratio techniques relied on evaluation of the overall size of the cardiac silhouette, without assessment of the cSAL and cLAL on both lateral and ventrodorsal radiographs. In contrast, our study design involved evaluation of the cSAL and cLAL relative to each other (cSAL:cLAL ratio and to the corresponding ML (short- and long-MHS) and also involved calculating the sum of the cardiac axes relative to the ML (overall-MHS) from measurements obtained from both right lateral and ventrodorsal thoracic radiographs. We used the ML, measured on the right lateral view, to normalize the lengths of the 2 cardiac axes measured on the lateral and ventrodorsal views because the manubrium was not easily outlined on the ventrodorsal radiographs. We identified that there were strong, significant correlations between the cSAL and the cLAL measured on the right lateral or ventrodorsal view and ML measured on the right lateral view. Stronger significant correlations were also identified between the sum of cSAL and cLAL (derived from both thoracic radiographic views) and the ML measured on the right lateral view. Furthermore, there was significant positive relationship between body weight and ML for each breed group. Normalization of cardiac dimensions of each individual by use of the ML was performed to reduce the relative variation that may exist as a result of combining different breeds into 1 of 2 groups of dogs.

With the VHS technique (involving the right lateral radiographic view), the dimensions of the cardiac silhouette were expressed by the number of midthoracic vertebrae starting at T4. However, the correlation between the VHS and the sum of the cSAL and cLAL measured on the right lateral view was weaker than the correlation between the VHS and the ML derived from that same view. This finding may be related to the relative variations in the vertebral size and shape among dog breeds and subsequent erroneous assessments of the cSALs and cLALs. Although it was not evaluated in the present study, the previously reported interobserver variability during the transformation of short- and long-axis dimensions into VHS units and in selection of anatomic reference points could be another potential reason. In that other study, the mean difference in VHS among 16 observers was 1.1 ± 0.3 vertebrae, with a coefficient of variation of 1.5% to 3.2%. Additionally, on the basis of the right lateral radiographic findings in this
study, the possible variation in the intervertebral disk spaces (eg, intervertebral disk space narrowing) may be another possible factor contributing to the relative weak correlation between the VHS and the corresponding cSAL and cLAL. However, the canine manubrium is rarely affected by disease, and it is a single prominent, elongated bone segment that can be easily identified on lateral thoracic radiographs. In addition, in the present study, there were strong correlations between the cSAL and cLAL and the corresponding ML. Therefore, we propose that the ML can be used as an appropriate reference value for assessment of the corresponding cSAL and cLAL in dogs. However, despite the fact that none of the examined large-breed dogs was excluded from the study, 3 of 60 (5%) small-breed dogs initially considered for study participation were excluded because of a deformed manubrium.

In a recent study in healthy dogs,\textsuperscript{16} cardiac cycle and, to a lesser extent, respiratory cycle were found to influence mean VHS. In the study reported here, we assumed that all radiographic views were obtained at end-inspiratory tidal volume; nevertheless, the effects of normal cardiac cycle and volume overload on the radiographic appearance of the heart should be considered when cardiac dimensions are evaluated by means of the proposed method. In addition, analysis of cardiac chamber contours as they appear on lateral and ventrodorsal radiographic views is still needed to distinguish between right- and left-sided cardiomegaly and determine which cardiac chamber is enlarged. The findings of the present report indicated that the cardiac silhouette appeared relatively more elongated on the ventrodorsal views, compared with its appearance on the right lateral views obtained from both large- and small-breed dogs. The radiographic appearance of the cardiac silhouette was relatively more round in small-breed dogs, compared with its appearance in large-breed dogs. The present study objectively evaluated the radiographic size and appearance of the cardiac silhouette in large- versus small-breed dogs and on right lateral and ventrodorsal thoracic radiographic views for each breed group. The differences in radiographic measurements between dogs with a wide thorax and dogs with a deep thorax or between males and females have been shown to not be significant.\textsuperscript{1,6,17,18} In 3 other studies\textsuperscript{13,19,20} that collectively calculated VHSs for large-, medium-, and small-breed dogs, the variables of age, sex, dog size, weight, and body condition score did not significantly influence the mean values of the VHS. However, body condition score had a significant effect on the VHS in the Lhasa Apso breed.\textsuperscript{8} The effects of these variables on measurements within each breed group in the present study were not analyzed. In the present study, the right lateral thoracic view was selected instead of the left lateral view because the cardiac silhouette appears round on left lateral thoracic radiographs, compared with its appearance on right lateral thoracic radiographs. Additionally, Buchanan and Bucheler\textsuperscript{4} found that right versus left lateral recumbency did not significantly influence radiographic measurements for VHS determination. However, Bavegems et al\textsuperscript{17} in 2005 and Greco et al\textsuperscript{19} in 2008 reported a significant difference in VHS determined by use of right or left lateral radiographs in dogs, with larger VHSs derived from right lateral views. In general, the relative enlargement of the cardiac silhouette on right lateral views in dogs may be attributable to the divergent x-ray beam and left-sided position of the heart within the thorax as well as the influence of the right-sided cardiac notch between the right cranial and right middle lung lobes.\textsuperscript{17} These factors also could be the reason for the relatively round appearance of the cardiac silhouette on left lateral thoracic radiographs.

A noticeable difference between the mean VHSs derived from dorsoventral and ventrodorsal radiographs of dogs has also been reported.\textsuperscript{1} The mean VHS for Whippets derived from ventrodorsal radiographs was significantly larger than that derived from dorsoventral views.\textsuperscript{17} This difference is related to the magnification and the elongated position and appearance of the heart on ventrodorsal radiographic views.\textsuperscript{1,17} Although the dorsoventral thoracic view was reported to be preferable over the ventrodorsal view for evaluation of cardiac size because of its relative lack of magnification,\textsuperscript{1} all the measurements were performed on ventrodorsal radiographs in the present study. The reason was that the ventrodorsal view together with right and left lateral views comprises the routine radiographic examination of the thorax of dogs and cats without severe respiratory distress in our clinic. In addition, the contours of the cardiac silhouette are more consistent and relatively less round on the ventrodorsal radiographs, compared with findings on the dorsoventral radiographs. To mitigate the differences in cardiac dimensions related to interbreed variation in the present study, the cSAL and cLAL (measured on the right lateral and ventrodorsal radiographs) were normalized by creating a ratio with the ML (measured on the right lateral radiograph). The relative increase in the cSAL:ML ratio and cLAL:ML ratio (short- and long-MHS, respectively) on the ventrodorsal view, compared with ratios derived from the right lateral view, may be a consequence of the magnification of the cardiac silhouette on the ventrodorsal radiographs. The VHS was not calculated on the ventrodorsal radiographs in the present study.

In a study of 100 clinically normal large- and small-breed dogs (weight range, 2 to 75 kg), the overall mean VHS was 9.7 (SD, 0.5), with a 95% CI of 8.7 to 10.7 vertebrae. In a subsequent study,\textsuperscript{19} the overall mean VHS collectively calculated for a group of 63 small-, medium-, and large-breed dogs was approximately similar (9.8 [SD, 0.6]). These relatively lower mean VHSs\textsuperscript{1,19} and a wider range of values in the first study,\textsuperscript{1} compared with the results of the present study, may be a reflection of the marked variations in the x-ray beam and left-sided position of the heart within the thorax as well as the influence of the right-sided cardiac notch between the right cranial and right middle lung lobes.\textsuperscript{17} These factors also could be the reason for the relatively round appearance of the cardiac silhouette on left lateral thoracic radiographs.
between dog breeds in these studies and the fact that the mean VHSs were determined for all dogs, regardless of breed size. In another study, the mean VHS for 85 clinically normal large-breed dogs (Boxers, Labrador Retrievers, German Shepherd Dogs, and Doberman Pinschers) was 10.5 (SD, 0.7), whereas the mean VHS for 42 clinically normal small-breed dogs (Cavalier King Charles Spaniels and Yorkshire Terriers) was 10.2 (SD, 0.5). In 2 other studies, mean VHSs for clinically normal German Shepherd Dogs and Beagles were 10.4 (SD, 0.4) and 10.9 (SD, 0.7), respectively. In a recent study, the mean VHS of 204 small-breed dogs (8 different breeds) was 10.5 (SD, 0.9). Mean VHSs of 10.3 (SD, 0.8) and 10.5 (SD, 0.7) have also been reported for clinically normal dogs of various breeds. These results are in reasonable agreement with the findings of the present study despite the greater breed variability within each breed group (20 different large and 24 different small breeds) in the present study, compared with breed variabilities in the previously reported studies.

The 95% CIs for the mean VHSs for the 60 clinically normal large- and the 60 clinically normal small-breed dogs (10.6 to 10.9 and 10.1 to 10.5, respectively) included in the present study have provided ranges of values that can be considered guidelines for radiographic assessment of cardiac silhouette size in healthy dogs. In accordance with the results of the VHS evaluation in the present study, cardiomegaly in large- and small-breed dogs could be considered when the sum of csAL and cLAL is > 10.9 thoracic vertebrae and > 10.5 thoracic vertebrae, respectively. These cutoff values are consistent with that determined in a previous study in which VHS > 10.7 was considered a moderately accurate sign of cardiac enlargement in a variety of dog breeds. In another study, a VHS of 10.5 was commonly recognized as a clinical and useful upper limit for normal heart size in most breeds of dogs. However, exceptions may exist in some breeds (eg, Boxer, Beagle, and Yorkshire Terrier) wherein a VHS value ≤ 11 was considered normal. This is relatively similar to the upper normal limit of VHS (10.9) determined for large-breed dogs in the present study. In our study, evaluation of thoracic radiographs obtained at different times from each dog was not done, as in other investigations. Echocardiography, however, remains the most accurate technique for diagnosis of cardiac diseases when associated clinical abnormalities or abnormal cardiac appearance exists on thoracic radiographs. In the present study, correlations between the standard VHS and the short-MHS, long-MHS, and overall-MHS were identified for large-breed dogs but not for small-breed dogs. Thus, for evaluation of cardiac dimensions in large-breed dogs, determination of VHS may be more convenient. However, we suggest that the overall-MHS could be considered for further evaluation in both clinically normal and ill dogs, regardless of breed size.

There remains a challenge in the radiographic assessment of heart diseases that develop without subsequent cardiac dilation, as in diseases with associated concentric hypertrophy of the left ventricle. Therefore, the use of the VHS and overall MHS in this situation would not reveal abnormalities. However, results of the previously reported radiographic techniques used to evaluate cardiac size in dogs and cats would also not be abnormal. For this reason, echocardiography remains the gold standard for diagnosis of cardiac diseases in dogs and cats.

The limitation of the study reported here was a lack of echocardiographic examinations to rule out subclinical cardiac diseases in the study dogs. However, in a previous study, cardiomegaly (confirmed via necropsy and echocardiography) in Greyhounds was easily assessed from thoracic radiographs with the VHS method. Given the VHSs for each breed group in the present study, we believe that the values obtained for the overall-MHS would be useful for future investigations of other clinically normal dogs (eg, medium-sized breeds) or dogs with cardiac disease. The present study was also limited in that interbreed variation within each breed group was not assessed. The inability to outline the manubrium on ventrodorsal radiographs is another limitation of the study reported here. This may explain the relative increases in short-MHS and long-MHS derived from the ventrodorsal radiographs, compared with values derived from the lateral radiographs, in the 2 breed groups. The inter- and intraobserver variability of the reported measurements was not evaluated and is considered an additional limitation of the present study. The usefulness of the MHSs for evaluation of cardiac dimensions in dogs with proven heart disease (based on clinical and echocardiographic assessments) warrants investigation, as does determination of correlations between the radiographic measurements evaluated in the present study and echocardiographic findings in such dogs.

Results of the present study indicated that the ML, as measured on right lateral thoracic radiographic views, is a possible reference value that could be used to normalize the measurements of width and height of the corresponding cardiac silhouette in small- and large-breed dogs. Despite the relative interbreed variations within each breed group in the present study, the csAL:cLAL ratio appeared to be useful in evaluating the normal size and appearance of the cardiac silhouette in each breed group. However, this ratio would not be expected to change if both the csAL and cLAL were to increase proportionally. Therefore, the ratio of the csAL to the cLAL should not be used alone to assess cardiac size in dogs. Upper and lower reference limits for overall-MHS in large- and small-breed dogs would need to be further evaluated with larger populations of clinically normal dogs, including the medium-sized breeds. Volume overload and normal cardiac cycle should also be considered when cardiac size and appearance are evaluated. Unlike findings for small-breed dogs, there were significant but weak, correlations between the VHS and MHS mea-
sured on right lateral and ventrodorsal radiographs obtained from large-breed dogs. The weakness and lack of correlations between the VHS method and the MHS method in large- and small-breed dogs, respectively, could be related to the variations in thoracic vertebral characteristics arising from common congenital, breed-associated, and acquired conditions that add unwanted variance to measures of cardiac size expressed as multiples of vertebral length. The MHS method relied on the length of a single reference bone segment (the manubrium), which correlated significantly with the corresponding lengths of the cardiac axes and with body weight, to evaluate cardiac dimensions on thoracic radiographs. Research is needed to demonstrate the usefulness of the MHS method for distinguishing between dogs with and without heart disease. Furthermore, the precision and accuracy of the technique, compared with those of the VHS method, should be investigated. Nevertheless, echocardiography remains the foremost diagnostic tool with which to confirm structural and physiologic abnormalities of the heart in dogs and other species.

Footnotes
a. CXDI-50G digital plate, Canon USA Inc, Lake Success, NY.
b. Merge PACs, Merge Healthcare Inc, Chicago, Ill.
c. Prism 6, GraphPad Software Inc, La Jolla, Calif.

References