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Evaluation of Four 2-Dimensional Echocardiographic Methods of Assessing Left Atrial Size in Dogs

Mark Rishniw and Hollis N. Erb

Two-dimensional (2D) echocardiography is the cornerstone of noninvasive evaluation of the cardiac patient, and often involves estimating left atrial (LA) size. However, 2D echocardiographic methods of estimating LA size have been inadequately described, and most reference intervals are based on M-mode echocardiographic measurements. We determined reference intervals for 4 different 2D echocardiographic methods of estimating LA size in adult (≥9-month-old) dogs without cardiovascular disease. Thirty-six dogs, placed in right lateral recumbency, were examined by 2D echocardiography. The left atrium was measured at specific time points in the cardiac cycle. Measurement methods were LA diameter in short axis, LA diameter in long axis, LA circumference in short axis, and LA cross-sectional area in short axis. Comparisons of these LA dimensions to appropriate aortic dimensions provided body weight–independent estimates of LA size. We found strong associations of LA dimensions with body weight (r^2 = .76–.88). Comparable body weight–independent 2D echocardiographic estimates of LA size in short axis exceeded historical M-mode reference intervals. These data provide echocardiographers with reference intervals for 2D echocardiographic estimates of LA size in adult dogs.

Key words: Canine; Cardiac; Echocardiography; Heart; Left atrium; Normal.

Echocardiography is the standard method for noninvasive assessment of cardiac function, anatomy, and pathology in domestic animals and humans. Standard imaging planes have been described for 2-dimensional (2D) echocardiography in dogs.[1] Similarly, cardiologists have developed guidelines for assessing function using M-mode echocardiography.

Evaluation of left-heart disease usually includes assessment of the size of the left atrium.[2] This evaluation allows the investigator to gauge the severity of the disease and the risk of developing left-sided congestive heart failure. In dogs, the risk of developing congestive heart failure increases with increasing left atrial (LA) size, because LA hypertrophy and stretch reflect increased LA pressure.[3] Several investigators have examined an M-mode method of estimating LA size in small animals based on a method used in human medicine.[4–6] Those investigators correlated LA short-axis diameter to body weight or body surface area, and also derived a body weight–independent measure of LA size (left atrium : aorta; [LA : Ao]).[6] A body weight–independent measure of LA size (such as LA : Ao) does not require a body weight measurement and, more importantly, provides a more consistent measure of LA size for any individual, because the aortic diameter in an adult dog would be expected to change less over time than body weight.

Unfortunately, the current M-mode method has inherent limitations. These include difficulty in reliably imaging the maximum diameter of the aorta and potentially transecting the left auricle (rather than the LA body) with the M-mode cursor. Consequently, many cardiologists and echocardiographers have resorted to measuring LA parameters by 2D echocardiographic imaging, which allows the echocardiographer to visualize and measure specific regions of the aorta and left atrium, thereby avoiding the potential limitations of the M-mode method. Some investigators proposed methods for 2D echocardiographic measurements of the left atrium, and performed preliminary evaluations of LA dimensions using long-axis views.[7,8] One group of investigators employed a 2D echocardiographic method to measure LA size, but examined only 1 breed predisposed to mitral valve degeneration (Cavalier King Charles Spaniel).[9–11] The methods have not been examined critically and, to our knowledge, reference intervals have not been established.[8]

The purposes of this study were to evaluate and describe 4 methods for assessing LA size in normal adult dogs using 2D echocardiography and to provide reference intervals for each method. We aimed to describe the relationship of LA dimension to body weight for each method. Further, we examined the relationship of LA dimensions to aortic dimensions to provide a body weight–independent means of assessing LA size.

From the Department of Veterinary Clinical Sciences (Rishniw) and Population Medicine and Diagnostic Sciences (Erb), New York State College of Veterinary Medicine, Cornell University, Ithaca, NY.

Reprint requests: Mark Rishniw, BVSc, MS, Box 34, Veterinary Research Tower, College of Veterinary Medicine, Cornell University, Ithaca, NY 14853; e-mail: mr89@cornell.edu.

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Materials and Methods

Data Acquisition

We examined 36 dogs (age: 0.75–16 years; weight: 4–55 kg) by 2D echocardiography. The dogs had normal cardiovascular physical examinations, no history of cardiac disease, and normal 2D and Doppler echocardiographic evaluations. We obtained the dogs from the hospital population of the Cornell University College of Veterinary Medicine Hospital for Animals with informed consent from the owners and did not exclude subjects on the basis of coexistent noncardiac disease. Most dogs included in the study were scheduled for elective neutering, had ocular disease, had mild orthopedic disease, or belonged to students and staff and did not have any identifiable diseases. Exclusion criteria included anesthesia within 48 hours of the echocardiographic evaluation, and other diseases that could affect blood volume.

One of us (MR) imaged each dog in right-lateral recumbency,[a] using previously published guidelines.[1,7] A short-axis right-sided parasternal view was obtained at the level of the aortic valve where commissures of the valve cusps were visualized during diastole. A long-axis right-sided parasternal 4-chamber view optimized for the left atrium and mitral valve was also obtained. We stored images of satisfactory quality in a cine-loop mode and then measured 3 consecutive beats online. We measured the left atrium by 4 methods.

Method 1—LA Short-Axis (LA_{SAX}) Diameter. We measured the internal short-axis diameter of the aorta along the commissure between the noncoronary and right coronary aortic valve cusps on the 1st frame after aortic valve closure (Fig 1A). We then measured internal short-axis diameter of the left atrium in the same frame in a line extending from and parallel to the commissure between the noncoronary and left coronary aortic valve cusps to the distant margin of the left atrium (Fig 1A). In images where a pulmonary vein was seen entering the left atrium at this caudolateral location, the edge of the left atrium was approximated by extending the visible edges of the left atrium in a curved fashion.

Method 2—LA Long-Axis (LA_{LAX}) Diameter. We examined 35 dogs by this method (1 dog could not be imaged in this plane because of technical difficulties). The 1st line crossed the mitral valve annulus in an image obtained just before opening of the mitral valve (just before early diastolic filling). A 2nd line bisected the annular (1st) line to the roof of the left atrium in an apicobasilar orientation, and a 3rd line approximately bisected the left atrium from the interatrial septum to the LA wall in a mediolateral orientation. The 3rd line provided the LA measurement (Fig 1B). We used the aortic measurements from method 1 because we could not visualize the aortic valve in the right-sided long-axis parasternal 4-chamber view.

Method 3—LA and Aortic Circumferences (LA_{CIRC}). We measured the internal short axis circumferences of the left atrium and aorta from the same frame as in method 1, using automated calculation software provided with the ultrasound machine (Fig 1C).

Method 4—LA and Aortic Cross-Sectional Areas (LA_{AREA}). We calculated the internal cross-sectional areas of the left atrium and aorta from the same image as in method 3, using automated calculation software provided with the ultrasound machine (Fig 1C).

Data Analysis

Data were normally distributed, and consequently were analyzed with parametric methods. We then analyzed the results in 2 ways.

Correlated to Body Weight. We averaged the measurements from 3 consecutive beats in each method for each dog to decrease the error of the measurements. We correlated the within-dog mean LA measurements with body weight for all dogs, and performed simple linear regression of the LA dimensions and the aortic short-axis diameter measurements on body weights and also used terms for body weight squared (Wt^2) for each method. The selection of simple or quadratic regression was based on the significance of the term for Wt^2 and visual inspection of the graphs of the standardized residuals plotted against the fitted values. We then derived expected means (and their 95% confidence intervals) for each variable at specific body weights from the appropriate regression equations (linear or quadratic) and tabulated these results (Appendix).

Normalized to Aortic Dimensions (Body Weight–Independent). For methods 1, 3, and 4, we formed beat-specific ratios of LA dimensions to the corresponding aortic dimensions. For method 2, we formed ratios of the individual LA_{LAX} diameter measurements to the aortic diameter measurements obtained from the short-axis view. We then calculated the means of the within-dog ratios for each method and described the variation and distribution of each of these mean ratios across dogs.

We examined the within-dog interbeat variability of the techniques by determining the within-dog variation for each measurement within each method. We did this by calculating the coefficient of variation for the 3 individual measurements obtained for the 3 consecutive beats. The coefficient of variation (SD/mean) was calculated for each variable for each dog, and then averaged for all dogs to obtain a coefficient of variation for each variable. We could not determine intraobserver or interobserver variability because all measurements were done in real-time (rather than off-line) and only 1 investigator measured the dimensions.

Results

Table 1 shows the characteristics of the dogs. Table 2 shows the descriptive statistics for the within-dog means for each LA : Ao ratio. Figure 2 shows the scatter plots for the 2 LA variables (LA_{SAX} and LA_{LAX} diameters) for which we used the quadratic equations (equations with Wt and Wt^2 terms). Figure 3 shows the simple linear regressions between the 2 LA variables and body weight for which the Wt^2 term could be ignored (LA_{CIRC} and LA_{AREA}). For all 4 LA variables, the adjusted r^2 values ranged from .76 to .88. Aortic short-axis diameter correlated well with body weight using a simple linear model (adjusted r^2 = .78; data not shown). The mean within-dog coefficients of variation for LA_{SAX} : Ao, LA_{LAX} : Ao, LA_{CIRC} : Ao, and LA_{AREA} : Ao were 6, 12, 6, and 9%, respectively.

Discussion

We have described four 2D echocardiographic methods for assessing LA size and have provided reference intervals for normal dogs. We correlated the measured variables to body weight and then to aortic dimensions (which provides a body weight–independent measure of LA size). Our results provide a basis for assessing LA size when examining dogs with left-heart disease by 2D echocardiography.

We found high but imperfect associations for all of the LA variables with body weight (LA_{SAX} diameter r^2 = .77; LA_{LAX} diameter r^2 = .88; LA_{CIRC} r^2 = .76; LA_{AREA} r^2 = .79; Fig 2). Aortic diameters correlated with body weight to a similar extent as previously identified, but no better than any other variable (aortic diameter r^2 = .78).[5] Several plausible reasons for the imperfect correlation of any cardiac variable with body weight exist. First, body weight in any individual animal can change over time, because it is dependent on the nutritional condition of the animal as well as on body frame size. Thus, 2 animals of the same body weight might have substantially different body frame sizes

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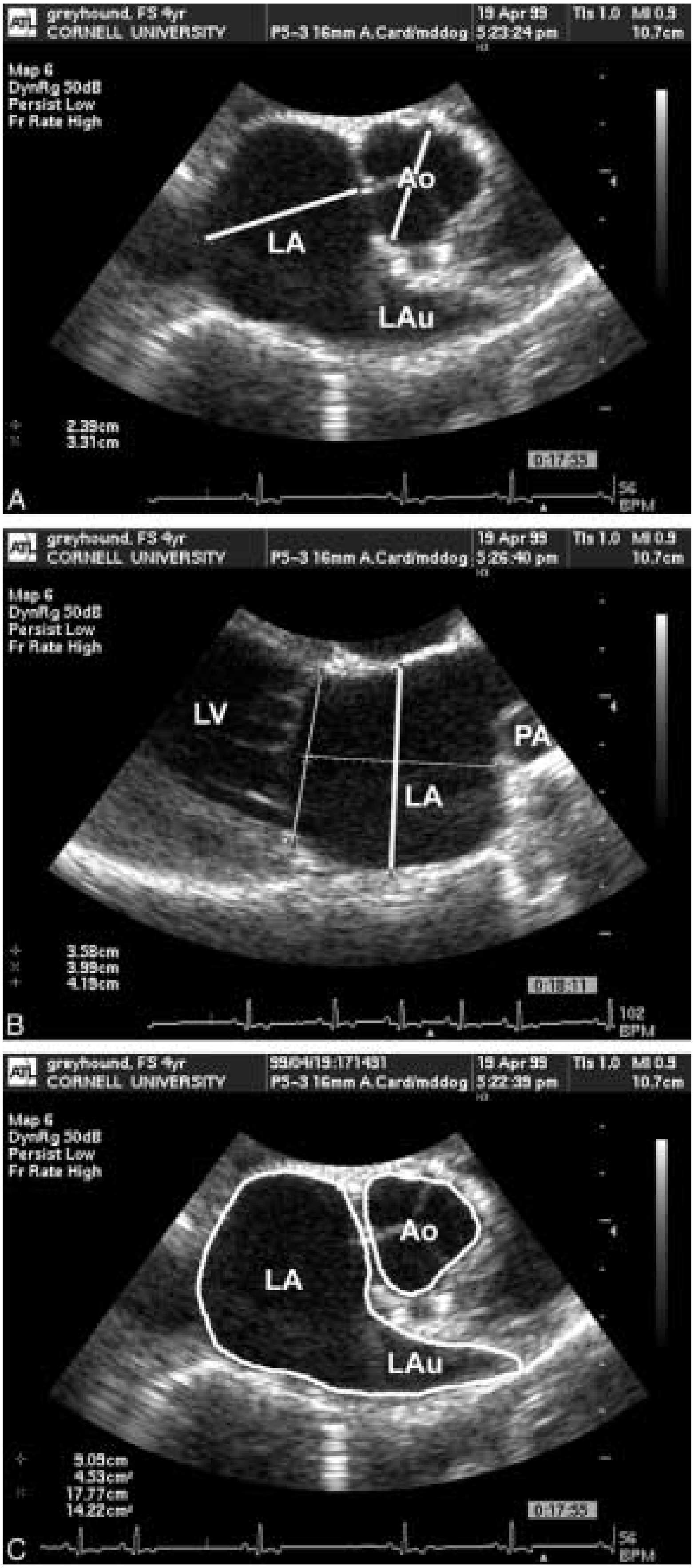
Fig 1. Examples of echocardiograms demonstrating the left atrial and aortic measurements. All images are optimized close-ups of the regions of interest. **(A)** Right-sided parasternal short-axis view with lines transecting the diameters of the left atrium and aorta, as used in method 1. The line through the left atrium extends from and parallel to the commissure of the aortic valve between the noncoronary and left-coronary cusps. **(B)** Right-sided parasternal long-axis view with lines delineating the mitral annulus, the apicobasilar axis of the left atrium, and the mediolateral axis of the left atrium (thick line), as used in method 2. **(C)** Right-sided parasternal short-axis view with outlines of the perimeters of the left atrium and aorta, as used in methods 3 and 4. Note the arrow on the ECG in each image indicating the frame selected is in the early diastolic phase of the cardiac cycle. Measurements, in centimeters, are included in the lower left corner of each image. LA, left atrium; Ao, aorta; LAu, left auricle; LV, left ventricle; RA, right atrium.


greyhound, FS 4yr
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P5-3 16mm A.Card/mddog
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TIs 1.0
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CORNELL UNIVERSITY
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Table 1. Descriptions of the 36 cardiologically normal dogs used to assess echocardiographic measurements of left atrial size.

Breed	Weight (kg)	Sex	Age (Years)
Australian Shepherd	20	FS	9
Australian Shepherd	25	MC	1.5
Basset Hound	13	FS	3
Beagle	7	FS	1
Border Collie	20	MC	16
Border Collie cross	33	FS	7
Borzoi	41	MC	3
Boston Terrier	6	FI	4
Boxer	20	FS	0.8
Boxer	30	MC	1
Dachshund	4	MI	>1
Dalmatian	21	FS	2
English Setter	30	MC	6
German Shepherd Dog	28	F	>1
German Shepherd Dog	40	MC	3
German Shepherd Dog cross	35	MI	>1
Golden Retriever	25	MC	1
Golden Retriever	32	MC	12
Great Dane	56	FS	5
Greyhound	30	FS	4
Irish Setter	25	MC	>1
Irish Wolfhound cross	23	FS	>1
Jack Russell Terrier	4	MC	0.8
Labrador Retriever	24	FS	1
Labrador Retriever	30	FS	13
Labrador Retriever	36	FS	3
Labrador Retriever	29	FS	4
Labrador Retreiver cross	19	MC	1
Labrador Retreiver cross	30	MI	0.8
Labrador Retriever × Border Collie	13	MC	0.8
Miniature Schnauzer	7	MC	10
Miniature Schnauzer	13	FS	2
Miniature Schnauzer	13	MI	5
Pit Bullterrier	20	MC	0.8
Poodle cross	17	FS	10
Shetland Sheepdog	9	MI	6

F, female; S, spayed; M, male; C, castrated; I, intact.

(eg, an obese 20-kg Cocker Spaniel has a body frame size that is different from an athletic 20-kg Border Collie, and would be expected to have a heart of a different size). Second, Morrison et al[12] showed that somatotype affected echocardiographic cardiac variables independently of body weight. Third, at least 2 dogs in our population were outliers: 1 was a Dalmatian and the other was an Irish Setter. However, we could not identify any pathology in these 2 dogs, and their body conditions were similar to the other dogs in the study. Therefore, they were not excluded from the analysis. Further, transient changes in blood volume due to mild dehydration or overhydration could alter atrial geometry from day to day. Finally, our sample group included only 2 dogs >40 kg; we suspect that these 2 dogs contributed to the need for 2 LA variables to have a quadratic term (Wt^2). These large dogs might not be representative of all dogs in this body weight range (40–55 kg), and might have skewed the data. Ultimately, however, our results merely underscore the degree of biological variability in a ''normal'' population.

We could not easily explain why aortic measurements in particular correlated no better with body weight than any other variable. We measured the aorta in a short-axis view, optimizing the image for the aortic cusp. Thus, the actual measurement location might have varied between the aortic annulus and the proximal portion of the aortic sinus, which is wider than the annulus.[8] This effect would increase the variability of the measurements, and decrease the correlation with body weight. Indeed, in Figure 1 the left coronary ostium is visible, suggesting an aortic sinus location for the aortic measurement in this, and potentially other, subjects.

We normalized LA size to the corresponding aortic dimension. Many echocardiographers normalize LA size to aortic diameters under the assumptions that few diseases change aortic diameter at the location at which it is measured, and that aortic diameter correlates better with body frame size than does body weight. Additionally, if comparing the LA size to the aorta provides a body weight–independent measurement (applicable for dogs of all sizes), the echocardiographer need only remember a single maximum value. Finally, aortic diameter is less likely to change over time than body condition in adult dogs, so comparisons in an individual animal over time might be more precise. Indeed, previous investigators demonstrated that no correlation occurred between LA:Ao and body weight, suggesting that this measurement of LA size was independent of body weight.[6,8]

As expected, our results for measuring LA_{SAX}:Ao are slightly larger than the results obtained previously by M-mode echocardiography. In our study, 100% of the dogs had LA_{SAX}:Ao <1.6 (Table 2), and the median (and mean) LA_{SAX}:Ao was 1.3. In previous M-mode echocardiographic studies, investigators generally accepted LA_{SAX}:Ao <1.3 as normal and mean LA_{SAX}:Ao was approximately equal to 1.0.[2,4–6] They adopted an M-mode method from human echocardiographic methods in which the M-mode cursor is directed across the short axis (or long axis) of the aorta and the body of the left atrium. However, this method has 2

Table 2. Descriptive statistics for the left atrium:aorta (LA:Ao) ratios of the 4 measurement methods (36 normal dogs).[a]

LA:Ao Variable	Percentiles 5th	25th	50th	75th	95th	Maximum
Diameter, short axis (method 1)	0.86	1.18	1.31	1.42	1.57	1.59
Diameter, long axis (method 2)	1.11	1.53	1.66	1.80	1.99	2.04
Circumference (method 3)	1.51	1.83	1.98	2.20	2.35	2.45
Area (method 4)	1.76	2.20	2.83	3.30	3.68	3.85

[a] For long-axis diameter measurements n = 35 dogs.

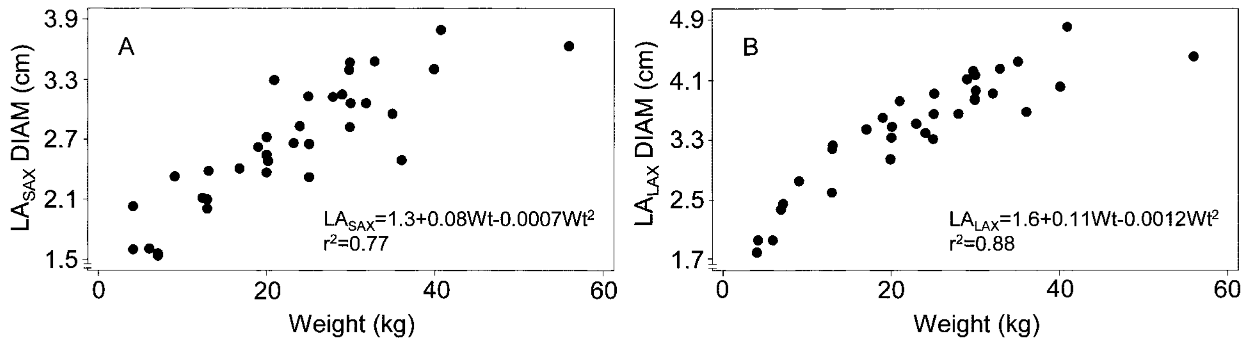

Fig 2. Scatter plots showing the distribution of data for left atrial short-axis and long-axis diameter versus body weight. The associations are nonlinear and no straight line of best fit could be approximated. Note that the central portion of the scatter plot is relatively linear, but deviates at greater body weights (and possibly at lower body weights). LA_{SAX} DIAM, left atrial short-axis diameter; LA_{LAX} DIAM, left atrial long-axis diameter.

potential limitations. First, the aorta might not be measured at its widest diameter in every instance. Additionally, the M-mode cursor often transects the left auricle (LAu) (rather than the body of the left atrium) in dogs because of different positioning of the heart compared to humans. Thus, previous investigators might sometimes have inadvertently compared the size of the left auricle and not the left atrium to the aorta. In normal dogs, the LAu_{SAX} : Ao would be expected to be smaller than LA_{SAX} : Ao. Our results support this hypothesis. Therefore, the traditional M-mode method of assessing LA size might be inaccurate in dogs with left-heart disease, because changes in left auricular size might not always accurately reflect changes in LA size. We believe that our methods circumvent this potential complication. However, we did not assess the accuracy of our methods in dogs with left-heart disease and are unable to determine whether or not our methods offer advantages in determining disease severity.

In one 2D echocardiographic study, investigators measured the LA and Ao diameters in a manner similar to method 1 in this study.[9–11] The aortic diameter was measured parallel to the LA diameter, rather than along the noncoronary/right-coronary cusps. This approach would minimally alter the aortic dimensions. The report omitted specific details of image optimization and standardization. In that study, mean (±SD) LA_{SAX} : Ao was 1.0 (±0.06), slightly smaller than that obtained in our study. However, these investigators examined only 1 breed of dog (Cavalier King Charles Spaniel). Further, the imaging planes in that study included visualization of the pulmonic valve, which requires an oblique view of the left atrium and aorta (ie, a view that is not parallel to the mitral annulus), and the left atrium is measured more dorsal to the plane obtained in our study. This method would decrease the size of the left atrium and consequently the LA : Ao ratio. We sought to standardize our measurement technique as much as possible, and obtain the largest LA diameter. We believe this approach will minimize the possibility of falsely increased measurements by clinicians.

In the other 2D echocardiographic study, investigators measured the LA and aortic diameters in a manner similar to method 2 in this study.[8] The aortic diameter was measured in the right parasternal long-axis left ventricle–outflow view, rather than in the short-axis view. The investigators observed a mean LA_{LAX} : Ao of 2.3 (95% CI = 1.8–2.94), which is somewhat larger than that obtained in our study (1.6; 95% CI = 1.1–2.0). This result most likely reflects the different locations used to measure the aortic dimension, and inherent limitations in estimating maximum aortic diameter in the long-axis view.

We found little intradog interbeat variability for any of the methods (all coefficients of variation were ≤12%), which suggests that the methods are repeatable when performed by a single experienced observer.

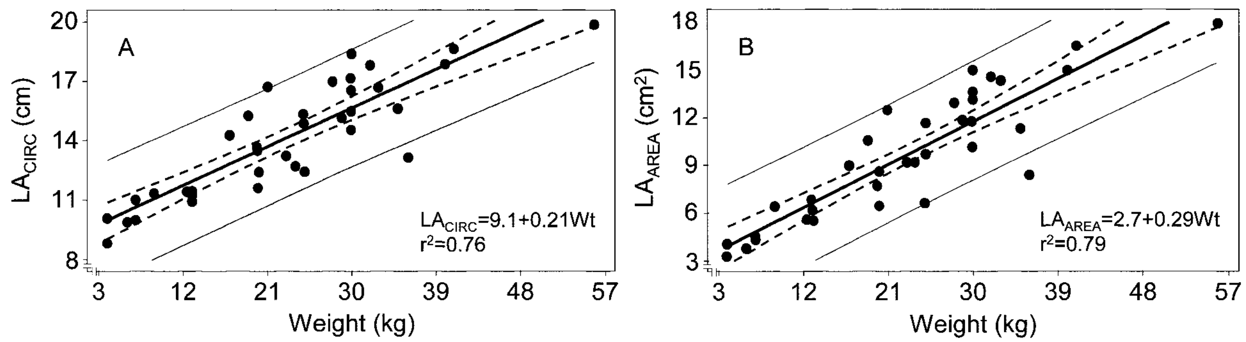

Fig 3. Linear associations of left atrial circumference or left atrial area and body weight. The heavy solid line represents the line of best fit, the dashed lines represent the 95% confidence intervals for the line of best fit, and the faint solid lines represent the 95% prediction interval for observations. LA_{CIRC}, left atrial circumference; LA_{AREA}, left atrial area.

Study Limitations

We standardized all measurements as much as possible. Ultimately, however, the exact frame in which we measured the left atrium and aorta was dependent on image quality. Therefore, not all measurements were obtained at exactly the same point within the cardiac cycle. We attempted to compensate for this variability by averaging 3 consecutive beats to reduce the variation of individual measurements. The small within-dog coefficients of variation suggested that measurements remained relatively constant between beats when measured by a single observer.

Interobserver variability could not be assessed because only 1 investigator measured the variables. Thus, assuming that the repeatability of the measurements might not be as high when this factor is taken into consideration is reasonable. Variables were not measured in a random or blinded fashion. However, each measurement was done independently of the others, and no attention was paid to the values while acquiring the data.

The methods we used require that relatively specific time points and regions be analyzed. We examined the LA diameter just before opening of the mitral valve or at the closure of the aortic valve (these time points are very close to each other, and minimal variation in atrial size at each of these points is expected). At this point in the cardiac cycle the left atrium should be most distended and should provide the largest normalized and absolute measurements. We also examined the left atrium at the level of the aortic valve in the short-axis view, and optimized for the mitral valve and left atrium in the long-axis view. Clinicians using the measurements we have provided must measure the regions of interest in the manner we have described. Measurements obtained at different time points and different locations should not be compared to our results.

Most dogs in our sample group were between 10 and 40 kg. Only 2 dogs were >40 kg and 6 dogs were <10 kg. Thus, our findings should be applied cautiously to dogs falling into the extremes of the body weight range used here and should not be applied to dogs that weigh less than or more than the dogs examined in this study. Dogs at either end of the body weight range evaluated in this study might not be representative of the population of dogs at these body weights. Indeed, we used the quadratic term (Wt^2) when examining the association of 2 of the LA variables with body weight, partly because of the values obtained from the 2 largest dogs. These dogs had atria that were smaller than predicted by the simple linear model. However, a simple linear relationship might exist if these dogs are not representative of the population of dogs at these body weights. The clinical impact of the quadratic term at body weights <40 kg is minimal, but becomes relevant (ie, differences of >1 cm) at larger body weights. Some investigators have shown a nonlinear relationship between cardiac dimensions and body weight in dogs throughout their postnatal growth period, but the nonlinear relationship was observed primarily at very young ages (with animals of smaller body weights), and relatively linear associations were found in older dogs (with greater body weights).[13,14] Other investigators demonstrated a linear relationship between cardiac dimensions and body weight for adult dogs weighing 4.5–30 kg, similar to our observations.[8]

Finally, we have not examined dogs with left-heart disease. However, even in dogs with left-heart disease, atria that measure within the limits we have described would be considered normal sized. Further studies in dogs with left-heart disease are needed to qualify degrees of LA enlargement.

Our results provide reference intervals for normal LA measurements. Left atria that measure substantially larger than the limits provided here are likely to be enlarged. Clinicians can then assess the degree and clinical importance of enlargement qualitatively.

Footnote

[a] ATL HDI 3000 with 7-MHz and 5-MHz phased-array sector scanners, ATL, Bellvue, WA

Acknowledgment

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Appendix. Predicted mean (95% CI) for each method at different body weights.[a]

Weight (kg)	LA_{SAX} Diameter (cm)	LA_{LAX} Diameter (cm)	LA_{CIRC} (cm)	LA_{AREA} (cm^2)
5	1.7 (1.0, 2.3)	2.1 (1.6, 2.7)	10.2 (7.2, 13.2)	4.2 (0.4, 8.0)
10	2.0 (1.4, 2.6)	2.6 (2.1, 3.2)	11.3 (8.3, 14.2)	5.72 (2.0, 9.5)
15	2.3 (1.7, 2.9)	3.1 (2.5, 3.6)	12.3 (9.4, 15.3)	7.2 (3.5, 10.9)
20	2.6 (2.0, 3.2)	3.4 (2.9, 4.0)	13.4 (10.5, 16.3)	8.7 (5.0, 12.4)
25	2.9 (2.2, 3.5)	3.7 (3.2, 4.3)	14.5 (11.6, 17.4)	10.2 (6.5, 13.9)
30	3.1 (2.5, 3.7)	4.0 (3.5, 4.5)	15.6 (12.6, 18.5)	11.7 (8.0, 15.4)
35	3.3 (2.6, 3.9)	4.2 (3.6, 4.7)	16.6 (13.7, 19.6)	13.2 (9.5, 16.9)
40	3.4 (2.8, 4.2)	4.3 (3.8, 4.8)	17.7 (14.7, 20.7)	14.7 (10.9, 18.5)
45	3.5 (2.9, 4.2)	4.4 (3.8, 4.9)	18.8 (15.7, 21.9)	16.2 (12.3, 20.1)
50	3.6 (2.9, 4.3)	4.4 (3.8, 5.0)	19.9 (16.7, 23.0)	17.7 (13.8, 21.7)
55	3.6 (2.9, 4.4)	5.4 (3.8, 5.1)	20.9 (17.7, 24.2)	19.2 (15.2, 23.3)

LA_{SAX}, left atrial short-axis; LA_{LAX}, left atrial long-axis; LA_{CIRC}, left atrial circumference; LA_{AREA}, left atrial area.

[a] Values were calculated from the regression equations for each variable. For LA_{SAX} diameter and LA_{LAX} diameter, quadratic functions were used (see Fig 2). For LA_{CIRC} and LA_{AREA}, linear functions were used (see Fig 3). Note that only 2 dogs weighed $>$40 kg, so predicted values for weights $>$40 kg should be used with caution.