Two-dimensional echocardiographic left-atrial-to-aortic ratio in healthy adult dogs: a reexamination of reference intervals*,#

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Cardiomegaly;
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Abstract Introduction: Left atrial-to-aortic ratios (LA:Ao) provide a body weight independent estimate of left atrial size. However, reference intervals were established with small sample populations and for only single points in the cardiac cycle. More robust reference intervals are warranted.

Animals: Two hundred and thirty eight apparently healthy adult dogs.

Materials and methods: LA:Ao measurements were obtained at 3 points in the cardiac cycle — maximal dimension, at the closing of the aortic valve (or just before opening of the mitral valve) (LA:AoMAX); minimal dimension, at the onset of the
QRS complex (LA:AoMIN) and at the onset of atrial systole (LA:AoP). LA:AoMAX was obtained from right parasternal short and long-axis views, and LA:AoMIN and LA:AoP were obtained from the right parasternal short-axis view. Dogs were excluded from analyses of reference intervals if weight-based left atrial and left ventricular diastolic dimensions exceeded reference interval limits. Effects of breed and body weight on LA:Ao measurements were examined.

**Results:** Upper LA:Ao reference limits mostly agreed with previously published limits, although 10% of dogs had LA:AoMAX in the short-axis view exceeding 1.6. These dogs had smaller aortae than expected for their body weight, and included mostly boxers and English setters. Reference limits for LA:AoMIN and LA:AoP were smaller than those for LA:AoMAX in either view. No LA:Ao measurements were associated with body weight.

**Conclusions:** Reference limits were either confirmed or established for the common two-dimensional methods of assessing relative left atrial size in healthy dogs. Clinicians should use caution when diagnosing mild left atrial enlargement in certain dog breeds and should examine the weight-based aortic dimensions in such cases.
Therefore, we sought to reassess the LA:Ao reference limits for dogs using a larger cohort and multiple investigators. Furthermore, we hoped to provide reference limits for measurements obtained at various points in the cardiac cycle and from two right-sided views. As secondary aims, we also examined left atrial dimensions, indexed to body weight, or a weight-adjusted aortic dimension.

Animals, materials, and methods

Cardiologists and clinicians with practice limited to cardiology provided data from apparently healthy adult dogs (>1 year). All dogs underwent a full echocardiographic evaluation after obtaining a brief history and performing a physical examination. Most dogs were presented for evaluation in cardiac screening clinics or for other studies of cardiac health and disease; 52 dogs were included from a previously published prospective study of left atrial function [9]. Data were collected prospectively from all dogs and included breed, age at examination, sex, weight, all left atrial measurements, aortic measurements, and left ventricular diastolic measurements. Dogs had no history of cardiac disease or any other disease that would be expected to affect cardiac function. Body condition scores were not recorded for any dogs.

Echocardiography

Measurement planes

All left atrial and aortic measurements were obtained from two-dimensional images from three cardiac cycles and averaged; all left ventricular dimensions were measured from M-mode images from three cardiac cycles and averaged. The left atrium was imaged from the right parasternal short-axis and right parasternal long-axis 4-chamber view; the aorta was imaged only from the short-axis view at the level of the valve cusps as described previously [2]. The left atrium in short axis was measured along a line extending from, and parallel to, the commissure of the aortic valve separating the left coronary and noncoronary cusps, as described previously [2]. The left atrium in long axis was measured midway between the mitral valve annulus and the roof of the left atrium, along a line that extended from the interatrial septum to the lateral left atrial wall, approximately parallel to the mitral annulus, as described previously [2]. Left ventricular diastolic dimensions were obtained from the short-axis view at the tips of the papillary muscles, just apical to the chordal insertions at the onset of the QRS complex. Cursors for all measurements were placed at the tissue–blood interface [11], as described previously [2].

Measurement timing

All studies were performed with simultaneous ECG monitoring, using a variety of ultrasound machines and probes. Left atrial and aortic measurements were obtained at three points in the cardiac cycle: at the onset of ventricular diastole, defined as the first measurable frame after aortic valve closure (in the short-axis view) (LAMAX and AoMAX), the onset of atrial systole (LAP and AoP), defined as the peak of the P wave on the ECG, and at the onset of ventricular systole (LAMIN and AoMIN), defined as the onset of the QRS complex. In the right parasternal long-axis view, the left atrium was measured only at the onset of ventricular diastole (LAMAX), defined as the last measurable frame before mitral valve opening [2].

We used two measures of cardiac size to define ‘normality’ for our cohort. First, we calculated the weight-indexed left ventricular (wLVIDd), left atrial (wLA) and aortic (wAo) dimensions as previously described [1]. We then ascribed each dog a value of ‘0’ if wLVIDd and wLA were within previously defined limits (1.95 for wLVIDd and 1.56 for wLA), and ‘1’ if they exceeded one of these limits. Dogs were excluded if they scored ‘2’ (i.e., exceeded the limits for both measurements), but were included if they scored ‘0’ or ‘1’.

We then calculated the LA:Ao for the three points in the cardiac cycle as defined previously. We used the aortic measurement obtained at that same point for calculating the respective LA:Ao, for example, both the left atrial and aortic measurements for the onset of atrial systole (LAP) were obtained at the peak of the P wave. We calculated the LA:Ao for the right parasternal long-axis view using the aortic measurement obtained at the onset of ventricular diastole (AoMAX) in the short-axis view.

Statistical analyses

We first examined whether investigators submitted similar LA:Ao estimates by plotting and visually comparing the LA:Ao data provided by each investigator. We further compared the LA:Ao, including wLA estimates, with Kruskal Wallis test and post hoc multiple comparison tests where indicated. We did not adjust the nominal alpha value (0.05) for these 4 comparisons. Because wAo measurements appeared to be impacted by breed, but because data for those breeds were provided
largely by one investigator (investigator 1), we examined whether investigator 1 provided smaller Ao measurements than the other investigators with an analysis of variance, followed by a Dunnett’s test, comparing each of the other investigators to investigator 1. We did this with and without the ‘impacting breeds’ included in the analysis under the assumption that, if the investigator, and not the breed, was responsible for our observations, we would detect differences between investigator 1 and the other investigators in both instances.

To further assess whether investigator 1 inadvertently biased the data set by measuring differently from other investigators, we performed an interobserver agreement analysis. Four investigators submitted right parasternal short axis images from 10 cases (3 images per case; total 120 images) to an online repository as DICOM files. All investigators then measured the aortic and left atrial dimensions, and investigators’ average measurements for each image set were compared via a repeated measures analysis of variance with post hoc multiple comparisons. We calculated the average coefficient of variation between all investigators and the maximum difference for each image set.

Because cardiologists commonly index left atrial measurements to body weight using an allometric scaling approach, we examined the relationships between LA, or Ao dimensions (at each time point) and body weight, and provided the scaling constants and exponents for each of these relationships [12].

We then used an open-source application to calculate reference intervals for all variables [13]. We chose the nonparametric method to determine reference intervals using the entire eligible data set. However, because investigator 1 contributed approximately 50% of the observations, we also calculated upper reference limits (which are most often used clinically) after excluding the data provided by investigator 1, to determine whether investigator 1 excessively biased the reference intervals.

We also examined associations between LA:Ao measurements and body weight by scatter plots and correlation analyses, and between LA:Ao measurements and breeds by visually examining the data. We additionally examined the relationship between weight-based aortic measurements and maximal LA:Ao (LA:AoMAX). All statistical analyses were performed using commercially available statistical software.8

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Results

Six investigators submitted data from 238 healthy adult dogs for the study. We excluded five dogs based on our echocardiographic criteria (wLVIDd and wLA both exceeded reference limits), although none of these dogs appeared to have cardiac disease. These five dogs were all examined by the same investigator. Three were young, small mixed-breed dogs and two were middle-aged English setters. Data for these five dogs are provided as an online supplement (Supplemental Table 1). Therefore, we ultimately analyzed data from 233 dogs. We did not have the data on the weight for one dog and lacked the long-axis measurements for one dog—these two dogs were excluded from the relevant analyses. Of the dogs included in the analyses, six had wLAMAX > 1.56 and 26 had wLVIDd > 1.95, but no dogs had both variables above the reference limits.

The remaining 233 dogs comprised 56 breeds and mixed-breed dogs (Supplemental Table 1), weighed a median of 18.5 kg (range: 2.5–62 kg, IQR: 11–28 kg) with approximately equal sex distributions (female: 78, spayed female: 44, male: 91, neutered male: 25).

Investigators did not differ between LA:Ao measurements that they submitted, except for LA:Ao measured at the P-wave (LA:AoP). For this variable, one investigator submitted slightly higher LA:AoP measurements than three other investigators (p = 0.02) (Fig. 1, Table 1).

The reference intervals for the four LA:Ao measurements, and for wLVIDd are provided in Table 2. The regression coefficients for LA measurements, indexed to body weight, and the upper reference limits derived from these are provided in Table 3.

Twenty-eight dogs had LA:AoMAX (RPSA) > 1.6, and seven dogs had LA:AoMAX (RPSA) > 1.7 (Fig. 2A). When we examined the LA:AoMAX data by breed, we identified 3 breeds which appeared to account for 50% of high LA:AoMAX (RPSA) values: beagles (2/3), boxers (7/16), and English setters (5/19) (Fig. 2B), although 3 of the English setters were excluded from the initial analyses because they exceeded the wLA and wLVIDd limits. We recalculated the reference intervals after removing these three breeds. This decreased the upper limit from 1.73 to 1.66 (90% CI: 1.63–1.75).

None of the LA:Ao variables or weight-based left atrial (wLA) or aortic (wAo) variables showed any association with body weight (largest r for any association = 0.17; Supplementary Fig. I).

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8 MedCalc, version 18.10.2, MedCalc Software bvba, Ostend, Belgium.
We found that LA:Ao MAX (RPSA) had a modest negative relationship with weight-indexed aortic measurements (wAo) — dogs with smaller aortae for their weight tended to have larger LA:AoMAX (RPSA) measurements ($r = 0.49$, $p < 0.05$; Fig. 3). All dogs ($n = 28$) with LA:Ao > 1.6 had wAo < 1.0; 25/28 had wAo < 0.9. However, many dogs with wAo < 1.0 had LA:Ao < 1.6. When plotted against body weight, the wAo were consistently < 0.9 in two breeds identified as having large LA:AoMAX — beagles and boxers. English setters had wAo that were scattered across the range of values (Supplementary Fig. II). However, all the English setters with LA:Ao exceeding 1.6 had wAo < 0.9, similar to boxers and beagles.

Because a single investigator (investigator 1) provided most of the data for boxers and English setters, we examined whether this investigator simply imaged and measured aortic valves differently from the other investigators. We found that measurements of investigator 1 were smaller only than those of investigator 4, who had the largest measurements (on average). Furthermore, after measurements obtained from boxers were removed from the analysis, we observed no differences in measurements between investigator 1 and the other investigators.

In addition, investigator 1 did not measure the same images differently from other investigators. Investigator 5 measured aortae larger than those measured by all other investigators ($p < 0.05$ for all pairwise comparisons). The average interobserver coefficient of variation for measuring aortic dimensions was 5.3% (median 4.9%). The average maximum difference for measurements between investigators was 1.1 mm (median 1.0 mm) with the largest maximum difference for any image being 2.63 mm (for an aorta that measured 24 mm).

**Table 1** Summary statistics for right parasternal short-axis LA:AoP measurements provided by 5 investigators.

<table>
<thead>
<tr>
<th>Investigator</th>
<th>n</th>
<th>Minimum</th>
<th>25th %</th>
<th>Median</th>
<th>75th %</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>131</td>
<td>0.97</td>
<td>1.25</td>
<td>1.39</td>
<td>1.49</td>
<td>1.99</td>
</tr>
<tr>
<td>2</td>
<td>43</td>
<td>0.97</td>
<td>1.24</td>
<td>1.30</td>
<td>1.39</td>
<td>1.80</td>
</tr>
<tr>
<td>3</td>
<td>17</td>
<td>1.09</td>
<td>1.20</td>
<td>1.29</td>
<td>1.32</td>
<td>1.50</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>1.00</td>
<td>1.15</td>
<td>1.41</td>
<td>1.53</td>
<td>1.70</td>
</tr>
<tr>
<td>5</td>
<td>23</td>
<td>1.09</td>
<td>1.22</td>
<td>1.26</td>
<td>1.32</td>
<td>1.62</td>
</tr>
<tr>
<td>6</td>
<td>13</td>
<td>1.07</td>
<td>1.29</td>
<td>1.37</td>
<td>1.43</td>
<td>1.54</td>
</tr>
</tbody>
</table>

Investigator 1 differed from investigators 2, 3, and 5 ($p = 0.02$).

LA:AoP: Left atrial-to-aortic ratio measured at the onset of atrial systole.
Discussion

Our study suggests that the previous upper reference limit for two-dimensionally measured LA:AoMAX of 1.6, obtained from the right parasternal short-axis view, is reasonable, but might slightly underestimate the true range, resulting in misdiagnosis of some healthy dogs with LA:AoMAX slightly exceeding this limit as having left atrial enlargement. In our present study, approximately 10% of apparently healthy dogs exceeded this limit. Our study augments previous research by providing reference limits for LA:Ao measurements obtained during different points in the cardiac cycle, provides more robust data for left atrial dimension indexed to the weight-based aortic dimension (wLA), and provides novel data for the left atrial dimensions indexed to body weight. We identified at least two breeds in which the LA:Ao measurements exceeded traditional reference limits [2,3] in a moderate proportion of the individuals: boxers and English setters. Therefore, clinicians should perhaps interpret LA:Ao measurements cautiously when examining individuals of these breeds. Whether similar issues exist with breeds absent from our study, or represented by too few individuals (e.g., beagles), remains to be determined.

Our study also provides reference limits for LA:Ao measured during different points in the cardiac cycle, and from the right parasternal long-axis view. Some clinicians have proposed that the right parasternal long-axis view is superior to the short-axis views because it avoids measurement into the pulmonary venous ostia, especially in dogs with left atrial enlargement [7]. Others have suggested that measuring the left atrium and aorta in the short-axis view at the end of ventricular

Table 2  Reference limits for LA:Ao measurements obtained from 2 views at different points in the cardiac cycle from 233 healthy adult dogs.

<table>
<thead>
<tr>
<th>Variable (measurand)</th>
<th>Lower reference limit</th>
<th>90% Confidence interval of the lower reference limit</th>
<th>Upper reference limit</th>
<th>90% Confidence interval of the upper reference limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA:AoMAX (RPSA)</td>
<td>1.05</td>
<td>0.97–1.10</td>
<td>1.73</td>
<td>1.67–1.76</td>
</tr>
<tr>
<td>LA:AoP (RPSA)</td>
<td>1.04</td>
<td>0.97–1.08</td>
<td>1.70</td>
<td>1.62–1.83</td>
</tr>
<tr>
<td>LA:AoMIN (RPSA)</td>
<td>0.86</td>
<td>0.75–0.94</td>
<td>1.53</td>
<td>1.48–1.65</td>
</tr>
<tr>
<td>LA:AoMAX (RPLA)</td>
<td>1.40</td>
<td>1.33–1.49</td>
<td>2.11</td>
<td>2.07–2.17</td>
</tr>
<tr>
<td>wLA</td>
<td>0.97</td>
<td>0.92–1.07</td>
<td>1.57</td>
<td>1.54–1.62</td>
</tr>
<tr>
<td>nLAMAX (RPSA)</td>
<td>0.72</td>
<td>0.7–0.8</td>
<td>1.17</td>
<td>1.15–1.2</td>
</tr>
<tr>
<td>nLAMIN (RPSA)</td>
<td>0.53</td>
<td>0.47–0.55</td>
<td>0.89</td>
<td>0.85–0.92</td>
</tr>
<tr>
<td>nLAP (RPSA)</td>
<td>0.65</td>
<td>0.58–0.7</td>
<td>1.07</td>
<td>1.05–1.09</td>
</tr>
<tr>
<td>nLAMAX (RPLA)</td>
<td>1.15</td>
<td>1.09–1.17</td>
<td>1.73</td>
<td>1.64–1.79</td>
</tr>
</tbody>
</table>

LA:Ao: Left atrial-to-aortic ratio; RPSA: Right parasternal short-axis view; RPLA: Right parasternal long-axis view; LA:AoMAX: Left atrial-to-aortic ratio measured at the maximal left atrial diameter (early diastole); LA:AoMIN: Left atrial-to-aortic ratio measured at the onset of ventricular systole; wLA: left atrial-to-weight-based aortic ratio; nLAMAX: maximum left atrial diameter indexed to body weight; nLAMIN: minimal left atrial diameter indexed to body weight; nLAP: left atrial diameter at the onset of atrial systole indexed to body weight.

Table 3  Scaling exponents, proportionality constants and upper reference limits for canine left atrial measurements indexed to body weight obtained from 233 dogs.

<table>
<thead>
<tr>
<th>Variable (measurand)</th>
<th>Scaling exponent (b) ( ^{a} )</th>
<th>Proportionality constant (m) ( ^{a} )</th>
<th>Upper reference limit</th>
<th>90% Confidence interval of the upper reference limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>nLAMAX (RPSA)</td>
<td>0.355</td>
<td>0.989</td>
<td>1.17</td>
<td>1.15–1.2</td>
</tr>
<tr>
<td>nLAP (RPSA)</td>
<td>0.346</td>
<td>0.937</td>
<td>1.07</td>
<td>1.05–1.09</td>
</tr>
<tr>
<td>nLAMIN (RPSA)</td>
<td>0.387</td>
<td>0.845</td>
<td>0.89</td>
<td>0.85–0.92</td>
</tr>
<tr>
<td>nLAMAX (RPLA)</td>
<td>0.31</td>
<td>1.14</td>
<td>1.73</td>
<td>1.64–1.79</td>
</tr>
</tbody>
</table>

RPSA: Right parasternal short-axis view; RPLA: Right parasternal long-axis view; nLAMAX: maximum left atrial diameter indexed to body weight; nLAMIN: minimal left atrial diameter indexed to body weight; nLAP: left atrial diameter at the onset of atrial systole indexed to body weight.

\( ^{a} \) Scaling exponent and constant fit the regression equation \( Y = mx^b \).
diastole or onset of atrial systole provide clearer images of the aorta and left atrium (Luis Fuentes, personal communication). Therefore, our study provides reference intervals for clinicians who prefer to use time points or views that differ from the traditional method (LA:AoMAX(RPSA)).

Our finding that LA:AoMAX, obtained from the right parasternal short-axis view, might exceed 1.6 in approximately 10% of dogs has clinical implications. Several studies have used reference limits of 1.5 or 1.6 when determining left atrial enlargement [14–18]. This would tend to increase the number of dogs falsely identified as having mild left atrial enlargement. Indeed, a recent study defined ‘mild enlargement’ as LA:Ao between 1.5 and 1.7 [14]. The authors of that study, however, did not examine the agreement or accuracy of identifying ‘normal’ vs ‘mildly enlarged’ left atria – our data suggest that such accuracy would be low. Other studies have shown an increased risk of cardiac death in dogs with mitral valve disease when LA:Ao exceeds 1.7 [16].

Fig. 2  (A) Box and whisker plots of the left atrial-to-aortic ratio measurements, obtained in early diastole (LA:AoMAX), for every breed (and mixed-breed dogs) included in the study represented by more than one individual. The boxes denote the quartiles, the line denotes the median, the whiskers extend to 1.5 × the interquartile range and circles denote values falling outside of the whiskers. (B) Dot plots showing the distribution of LA:AoMAX for beagles, boxers, and English setters.

Fig. 3  Weight-based aortic (wAo) measurements plotted against left atrial-to-aortic ratios obtained from the right parasternal short-axis view in early diastole (LA:AoMAX) display a modest negative relationship. Most dogs with LA:AoMAX > 1.6 had a wAo < 0.9 (lower right quadrant), especially English setters (open squares), boxers (gray diamonds), and beagles (open triangles).
— that would seem intuitive, given our data suggesting that LA:Ao < 1.7 can be (and most probably is) normal in many dogs.

Whilst many of veterinary cardiologists use LA:AoMAX, other investigators routinely report the use of the minimal LA:Ao [19,20], or LA:AoP, and some do not report the exact technique used [21].

As previous studies [8] and our data show, these measurements are not interchangeable and inconsistency in acquisition or reporting could lead to the view and timing of their measurements of LA:Ao to avoid confusion and to maintain consistency. This should be performed both for clinical cases and studies describing LA:Ao measurements submitted for publication.

Recently, investigators examined the LA:AoMAX from the right parasternal long-axis view in 80 healthy dogs using two-dimensional echocardiography [7]. They measured the aorta from a long-axis view, rather than short-axis view, and obtained reference intervals slightly larger than those of our study or the original study by Rishniw and Erb [2] (2.4 vs 2.1). However, in the figures from that article, the authors appeared to measure the aorta during systole (valve cusps appear open in the representative figure) and the line of measurement appears to extend from cusp to cusp, rather than wall to wall. This would result in a potentially smaller aortic diameter than that obtained from the short-axis view, and therefore, would increase the resultant LA:Ao measurement.

Our data support and augment those of another recent study, where investigators determined left atrial and left ventricular reference intervals in 122 healthy adult dogs [4]. Our data are remarkably similar to those obtained by Visser et al [4], with few exceptions. The upper reference limits for LA:AoMAX are virtually identical. The scaling exponents for left atrial and left ventricular dimensions indexed to body weight in that study (0.309 and 0.299, respectively) mirror those from our study (0.31 and 0.295, respectively) and those of the left ventricular dimensions measured by Cornell et al [12](0.294). The upper reference limits for left ventricular dimensions indexed to body weight in that study (1.89 vs 1.85). However, the upper reference limits for left ventricle (LV) and left atrium (LA) indexed to body weight proposed by Visser et al [4] (1.67 and 1.65, respectively) are smaller than those in our study (and those proposed by Cornell et al [12]). Several reasons exist for these differences. First, Visser et al [4] had a single investigator perform all the imaging and another single investigator perform all the measurements. Any inherent, systematic measurement bias (or imaging bias) would remain undetected with such an approach. Second, interobserver variability is generally greater than intraobserver variability, which would result in a less variable data set from which to generate reference limits. Finally, the two studies used different methods to determine reference intervals — Visser et al [4] used a parametric approach that discarded the upper and lower 2.5th percentiles, while we used a nonparametric approach, which tends to give slightly wider reference intervals than parametric methods.

We had multiple investigators submit data. We did not examine all aspects of interobserver or intraobserver variability, as this has been examined for various echocardiographic variables previously, and for several of the investigators involved in our study [7,9,22–24]. Furthermore, unpublished data suggest that most cardiologists or clinicians routinely performing echocardiographic examinations obtain similar measurements for LA:Ao when measuring the same image from healthy dogs. In only one primary analysis (LA:AoP), did one investigator (investigator 1) provide measurements that differed statistically from three other investigators, but the magnitude of the difference was small (approximately 0.1 units), and not clinically important. Furthermore, when we examined the source of variation for this investigator, the wLA and LA were both smaller, rather than larger than most of the other investigators. Therefore, the reason for the larger LA:AoP was not a larger LA measurement, but a smaller AoP measurement. We examined the wAo and AoP measurements between investigators, and confirmed these suspicions. However, the other aortic measurements did not differ between investigators. When we examined whether investigator 1 consistently measured aortic valve dimensions smaller than other investigators, we found that this investigator differed only from one other observer, who tended to measure the dimensions larger than the other investigators. Because we could not all image the same dogs and compare images, we cannot rule out the possibility that Investigator 1 imaged dogs differently. However, this investigator did provide measurements for 12/16 boxers and 9/15 English setters. Of these, all 12 boxers and three English setters had
Importantly, the remaining four boxers, imaged by other investigators, also had wAo<0.91, and two other English Setters also had wAo<0.91. Consequently, the small difference between data submitted by the investigators could represent differences in aortic size of the sample populations, rather than biased measurement. When we excluded this investigator from the calculation of reference intervals, we found a small decrease in the upper reference limit for LA:AoP (from 1.70 to 1.65). Similarly, excluding these two breeds also decreased the upper reference limit for LA:AoP from 1.70 to 1.66. However, given that LA:Ao estimates are commonly reported to one decimal point, these differences would be abolished by ‘rounding’ of the values (producing an upper limit for LA:AoP of 1.7). Therefore, our data provide a generalizable evaluation of LA:Ao in healthy dogs, which can be reasonably extrapolated to the canine population at large.

One of the breeds that commonly exceeded the historical LA:AoMAX(RPSA) reference limit of 1.6 was the boxer. Previous studies have demonstrated that boxers have smaller aortae for their body weight than other breeds [25]. Our data support this observation, with all boxers in our study having wAo<1.0 and 13/16 having wAo<0.9. Examination of the data showed that, although wAo had no relationship with body weight, all but two boxers in our study showed wAo value less than 0.9 in a plot of wAo vs body weight (Supplementary Fig. II). Similarly, the English setters and beagles with large LA:Ao (>1.6) had wAo < 0.9, whereas English setters with normal LA:Ao had wAo > 0.9. This suggests that, rather than having large LA, some breeds, and some individuals within breeds have small aortae for their size. Indeed, all the dogs with LA:Ao >1.6 in our study, regardless of breed, had wAo <1.0 — in other words, their large LA:Ao was the result of a smaller-than-expected aorta, rather than a big left atrium. Therefore, clinicians might need to examine the aortic size for some dogs that appear to have mild or equivocal left atrial enlargement, based on LA:Ao calculations, before classifying such individuals as ‘abnormal’, especially if no other abnormalities can be detected. If an individual has a wAo that is < 1.0, clinicians should consider the possibility that the large LA:Ao is the result of a small aorta, rather than a big left atrium.

Somewhat surprisingly, 75% of our population had a wAo <1.0, and 62% had a wAo <0.95, regardless of their body weight or LA:AoMAX. This might suggest that our population was somewhat overweight (we did not estimate body condition scores for any dogs). However, boxers and English setters are not commonly overweight — indeed, the English setters were mostly hunting dogs, imaged by two investigators, and the boxers were imaged by two investigators. Therefore, these dogs might represent populations that truly have small aortae (on occasion) for their body size. We cannot, with our study design, completely rule out the effect of investigator or a breed-investigator interaction as a reason for our findings in English setters and boxers. However, our findings for boxers agree with the previous observations of aortic size.

We did not examine relationships with age or sex. We did not record hydration status or blood pressure for any dogs. Neither age nor sex has shown to affect the variables of interest. We had no reason to suspect that our cohort of apparently healthy dogs should have hypertension, or be dehydrated.

In conclusion, we present more robust reference intervals for LA:Ao in dogs from two views and three distinct diastolic time points. We have shown that previously published upper reference limits for LA:AoMAX might be slightly low and that LA:Ao obtained at different time points or from different views are not interchangeable.

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Conflicts of Interest Statement
The authors do not have any conflicts of interest to disclose.

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Supplementary data
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References


