Comparison Between Echocardiographic and Computed Tomographic Measurements of the Right Heart in Healthy Dogs

Vinicius B.C. SILVA, Stephany B. LUCINA, Danielle BUCH, Eloisa MUEHLBAUER, Tilde FROES, Marcela WOLF, Marlos G. SOUSA

Department of Veterinary Medicine, Universidade Federal do Paraná (UFPR), Rua dos Funcionários, Curitiba, Brasil


Abstract

Echocardiographic evaluation of the right side of the heart is limited by inherent difficulties in accessing views, and thus a variety of other diagnostic modalities, including computed tomography, have been proposed for right heart evaluation. The aim of this cross-sectional study was to review previously reported data and add computed tomography as a new tool for assessment of the right side of the heart, using echocardiography as a reference. Physical examination, electrocardiogram, echocardiogram, and thoracic computed tomography images were acquired in 6 healthy dogs. Structural assessments of the right atrium, the right ventricle, and the pulmonary artery were performed. Data from computed tomography were compared with conventional echocardiography. The agreement between the techniques was satisfactory for most of the evaluated parameters. There was no correlation between tomographic variables and weight and heart rate. Males had a higher mean basal right ventricle diameter (20.92 ± 1.45) compared to females (16.84 ± 0.03). There was a statistically significant difference between the medium right ventricle, right atrium, right ventricle free wall, aorta, pulmonary artery, and left ventricle diameters and the right ventricle/ left ventricle ratio between computed tomography and ultrasound. Good repeatability was found for the tomographic analyses, and the coefficients of variation were similar for most variables between the intraobserver and interobserver analyses. Computed tomography-derived measurements are simple to perform and have good repeatability and satisfactory agreement for most of the parameters evaluated on the echocardiogram.

Keywords: Imaging techniques, pulmonary artery, right atrium, right ventricle, structural assessment

Introduction

The morphofunctional assessment of the left heart is well established in human patients. However, in recent years, the right side has become the focus of research because it is directly or indirectly influenced by heart diseases and clinical conditions that affect the pulmonary vascular bed (Haddad et al., 2008). Right ventricle (RV) function and structure are difficult to quantify and assess, especially when compared to the left side of the heart. The challenges inherent to the evaluation of the right side of the heart include the complex three-dimensional shape and separate regions of inlet and outlet pathways, difficulty acquiring reliable images during echocardiographic examination, the prominent endocardial trabeculations, and the fact that the effects of high afterload are more significant on the right side (Voelkel et al., 2006).

In males, a number of indices for the quantitative assessment of right ventricle (RV) function have been published, and there are guidelines for the standardization of echocardiographic images that have been validated by more specific techniques such as catheterization or magnetic resonance imaging (Rudski et al., 2010). Fortunately, several of these assessments, mainly those focused on longitudinal systolic function (Visser et al., 2015), can be applied to dogs as well. A previous study defined reference intervals for the echocardiographic dimensions of the right heart in healthy dogs. The authors concluded that the repeatability of the analyses makes them suitable for clinical decision-making (Gentile-Solomon & Abbott, 2016).

The use of other diagnostic modalities, such as computed tomography (CT), has been proposed to overcome the limitations inherent to the evaluation of the right heart by echocardiographic examination. The first study using CT for cardiac structural assessment in dogs involved quantification of left ventricle (LV) mass and demonstrated accurate results and good reproducibility (Feiring et al., 1985). Over the years, CT has been increasingly used in routine practice. More recently, CT measurements of the diameters of the LV, left atrium (LA), aorta (Ao), and pulmonary artery (PA) and the ratio of Ao to PA have been compared to the echocardiographic examination of healthy dogs (Laborda-Vidal et al., 2015).

The aim of this study was to review the data reported so far and add CT as a new tool for assessment of the right heart of dogs through specific structural measurements, using echocardiography as a reference.

Material and Methods

This prospective, observational study, carried out in August 2020, included 6 healthy Beagle dogs admitted to the comparative cardiology laboratory of the veterinary teaching hospital and referred to a veterinary diagnostic center. All dogs underwent a complete
physical examination, including echocardiographic, electrocardiographic, and CT examinations. Electrocardiographic tracings (TEB - Tecnologia Eletrônica Brasileira, São Paulo, SP, Brazil) were obtained over a period of 3 minutes. All procedures were approved by the Ethics Committee on Animal Use (protocol 35-2019) and met the ARRIVE guidelines and Guide for the Care and Use of Laboratory Animals.

Exclusion criteria were animals with non-sinus arrhythmias and acquired and congenital heart diseases.

Echocardiography (Philips Affiniti 50—Ultrasound System Equipped with Transducers of 2–4, 3–8, and 4–12 MHz, Andover, MA, USA)
The echocardiographic examination was performed in all animals without the use of sedation, in right and left lateral decubitus, according to the recommendations of the Committee on Echocardiography of the Specialty of Cardiology of the American College of Veterinary Internal Medicine (Thomas et al., 1993).

The internal diameter, extending from its free wall to the interatrial septum, and length, extending from the tricuspid valve to the right atrial floor, of the RA were measured on two-dimensional images at the end of ventricular diastole. The following measurements of the RV were performed: basal internal diameter, extending from the free wall to the interventricular septum, immediately below the tricuspid annulus; medium diameter, located at the midpoint between the ventricular apex and the tricuspid annulus, extending from the free wall to the interventricular septum; length, from the ventricular apex to the tricuspid annular plane (next to the anterior leaflet); and the diameter of the free wall. All RV measurements were performed in diastole on the apical, four-chamber view optimized for the RV. The RV:LV ratio was calculated using the end-diastolic diameter measured in the apical 4-chamber view, which identified the maximum distance between the ventricular endocardium and the interventricular septum perpendicular to the long axis in the middle third of the chambers.

The diameter of the main PA was measured in the transverse axis of the pulmonary plane in the right parasternal window, just below the pulmonary valve, at the largest diameter of the vessel. In this same image, the diameter of the ascending Ao transversely sectioned was measured. A ratio of these measures was obtained through simple division.

Three measurements for each parameter were performed, and the mean value was used in the analyses. The echocardiographic parameters measured are shown in Figure 1.

Computed Tomography (Toshiba America Medical Systems—Helical Tomograph Alexion, Multislice, Four-Channel, Otawara, Japan)
For the CT examination, the dogs were anesthetized with a continuous infusion of propofol (Cristália-Propovan’, 10 mg/mL, Itapira, SP, Brazil) at a rate of 2 mg/kg/minute, intravenously, until the complete loss of laryngotracheal reflex, mandibular tone, and response to interdigital pinching in the forelimb allowed endotracheal intubation. The appropriately sized endotracheal tube for each animal was connected to a circular anesthetic circuit to provide a gas flow of 20 mL/kg and an inspired fraction of oxygen of 100%. The dogs were positioned in sternal decubitus and maintained on spontaneous ventilation. The inspired fraction of isoflurane (Cristália-Isoréine’, Itapira, SP, Brazil) was adjusted to 1V%, corresponding to the minimum alveolar concentration for the species. All images were obtained in cross-section with a slice thickness of 2 mm. The CT sweep settings were: 120 kVp and 150 mA, 0.75 second spin time, 360° sweep, 512 × 512 matrix, and 3.5 pitch. All sections were acquired using a standard soft tissue algorithm. The images were displayed at 40 Window Level (WL) and 400 Window Width (WW). Non-ionic iodinated contrast (Bayer S.A-Intravenous Iopromide 0.623 g Ultravist® 300, São Paulo, SP, Brazil) was manually injected intravenously at a dose of 300–400 mg/kg (2 mL/kg) for 3–5 seconds. The dogs were monitored for 30 minutes after the procedure for any adverse effects of the contrast, such as facial or body erythema, anaphylaxis, bradycardia, or hypotension.

The CT images were analyzed at a workstation with appropriate software for reading files in DICOM format (RadiAnt DICOM Viewer®) by an experienced observer blinded to the echocardiographic examination and a second observer with previous training who performed the echocardiograms. The multiplanar reconstruction images were created by simulating the echocardiographic images. Three measurements for each parameter were performed, and the mean of these was used in the analyses.

The tomographic variables followed those described for the echocardiographic examination and the measurements were performed without the aid of the electrocardiogram, using the maximum diameters of the structures under study, except for the RA. The tomographic parameters performed are shown in Figure 1.

Statistical Analyses
The Shapiro–Wilks test was used to verify the normality of the data. The results of parametric and nonparametric data from both CT and echocardiography are presented as mean and standard deviation or median and range, respectively. In the comparison analysis between tomographic and echocardiographic measurements, the paired t-test was used for samples with normal distribution, and the Wilcoxon test for samples with abnormal distribution. Pearson’s correlation (parametric data) or Spearman’s correlation (nonparametric data) were calculated to verify the influence of body weight and heart rate on all evaluated parameters. To verify the influence of sex on the studied variables, males and females were compared, using the t test in samples with normal distribution, and the Mann–Whitney U-test in samples with abnormal distribution. The Bland–Altman test was used to assess the agreement of the different variables studied regarding the 2 methods applied. For the repeatability study, the measurements were reassessed by the same observer, with a minimum interval of 30 days from the first assessment, and intraobserver variability was calculated. The same measurements were performed by a second observer, blinded to the results of the first investigation, to measure interobserver variability. All analyses were performed with the GraphPad Prism (GraphPad Inc, 9.0 version, La Jolla, CA, USA) software and p < .05 was considered significant.

Results
Six Beagle dogs were recruited for the study, of which 3 were female and 3 were male, all aged 48 months, with sinus arrhythmia and heart rhythm. The mean body weight was 12.93 kg (±1.80).
The agreement between the techniques was satisfactory for most of the evaluated parameters, as demonstrated by the Bland–Altman analysis (Table 1). For both methods, the greatest bias, which indicates the greatest mean difference, was $-7.283$ mm for the LV diameter, with a difference ranging from $-10.67$ to $-3.892$ mm.

Table 2 describes the data from CT and echocardiography, represented by the mean and standard deviation, or median and range. In the comparison between the 2 techniques, the middle RV diameter ($p = .0353$), RA diameter ($p = .0023$) and RV/LV ratio ($p = .0051$) were significantly greater when measured using CT, whereas the diameter of the RV free wall ($p = .0392$), LV diameter ($p = .0001$), and diameter of the Ao ($p = .0062$) and pulmonary arteries ($p = .0118$) were significantly greater when measured using echocardiography.

There was no correlation between tomographic measurements and weight and heart rate. However, in the echocardiographic measurements, there was a strong positive correlation between the RV free wall ($r = .8284; p = .0417$), the basal RV diameter ($r = .8853; p = .0190$) and the RA diameter with weight ($r = .9196; p = .0094$), as well as a strong negative correlation between RV diameter and heart rate ($r = -1.0; p = .0028$).

In the evaluation of the comparison of the variables studied between males and females, a statistical difference was identified only for the basal diameter of the RV ($p = .0083$) measured by CT, the mean of which was higher in males ($20.92 \pm 1.45$) in comparison to females ($16.84 \pm 0.03$).

Good repeatability was found for the tomographic analyses (Table 3). For the RV free wall, RA length, and LV diameter parameters, CVs were slightly higher in the interobserver assessment (CV: 10.55%, 19.48%, and 10.04%, respectively) compared to the intraobserver analysis (CV: 5.13%, 4.35%, and 3.88%, respectively). For the other parameters, CVs were similar between intraobserver and interobserver analyses.

**Discussion**

Computed tomography is not the technique of choice to assess RV shape and function, as it requires the use of contrast and ionizing...
radiation. However, because it is a modality routinely used in the evaluation of thoracic diseases, including those with potential repercussions for the right side of the heart, useful information can be extracted from this methodology if interpreted correctly (Bruzzi et al., 2006a, b).

In man, CT-derived values are already established for structural and functional evaluation of the right heart chambers in a healthy population (Lin et al., 2008). In veterinary medicine, there are few studies describing the right side of the heart. In this study, CT compared well with echocardiography as a reference method for most of the evaluated parameters, according to the results described by Bland–Altman analysis.

The evaluation of the right side of the heart with CT has already been described in dogs with pulmonary stenosis and coronary anomaly (Gunther-Harrington et al., 2019; Kim et al., 2021; Leblanc & Scollan, 2018; Sieslack et al., 2014), description of the PA/Ao ratio in healthy dogs (Granger et al., 2016) and in dogs with pulmonary hypertension (Sutherland-Smith et al., 2018) as well as RV/LV ratio in West Highland White Terriers with and without idiopathic pulmonary fibrosis (Soliveres et al., 2021). To the authors’ knowledge, the present study is the first to describe the relationship between echocardiographic and tomographic parameters for the structural evaluation of the RV, RA, and PA in healthy dogs.

For some measurements (Table 2), there was a statistical difference between the 2 techniques employed. This might be explained by differences in the temporal and spatial resolutions of the 2 modalities. Both the PA and Ao diameters were larger on echocardiography, but no difference was found in the ratio between the variables. The same reasoning applies to the LV diameter, which was larger on echocardiography, increasing the value of the RV/LV ratio on CT. Similarly, although CT provides accurate RV image quality, in a study in which RV volume was quantified by different techniques in healthy dogs, CT overestimated RV volumes compared to magnetic resonance imaging used as a reference method (Sieslack et al., 2014).

### Table 1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Biases</th>
<th>Limits of Agreement of 95%</th>
<th>SD of the Biases</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV free wall (mm)</td>
<td>−0.4917</td>
<td>−1.343 to 0.3592</td>
<td>0.4341</td>
</tr>
<tr>
<td>RV middle diameter (mm)</td>
<td>2.322</td>
<td>−1.573 to 6.217</td>
<td>1.987</td>
</tr>
<tr>
<td>RV basal diameter (mm)</td>
<td>−0.0388</td>
<td>−4.367 to 4.290</td>
<td>2.208</td>
</tr>
<tr>
<td>RV length (mm)</td>
<td>0.5278</td>
<td>−2.913 to 3.969</td>
<td>1.756</td>
</tr>
<tr>
<td>PA diameter (mm)</td>
<td>−1.822</td>
<td>−4.086 to 0.4412</td>
<td>1.155</td>
</tr>
<tr>
<td>Aortic diameter (mm)</td>
<td>−3.078</td>
<td>−6.343 to 0.1870</td>
<td>1.666</td>
</tr>
<tr>
<td>PA:Ao ratio</td>
<td>−0.2208</td>
<td>−0.4474 to 0.0057</td>
<td>0.1156</td>
</tr>
<tr>
<td>RA length (mm)</td>
<td>−0.0833</td>
<td>−3.275 to 3.108</td>
<td>1.628</td>
</tr>
<tr>
<td>RA diameter (mm)</td>
<td>4.606</td>
<td>0.7253 to 8.486</td>
<td>1.980</td>
</tr>
<tr>
<td>RV diameter (mm)</td>
<td>0.4556</td>
<td>−3.853 to 4.765</td>
<td>2.198</td>
</tr>
<tr>
<td>LV diameter (mm)</td>
<td>−7.283</td>
<td>−10.67 to −3.892</td>
<td>1.730</td>
</tr>
<tr>
<td>RV:LV ratio</td>
<td>0.2237</td>
<td>−0.0023 to 0.4498</td>
<td>0.1153</td>
</tr>
</tbody>
</table>

Note: Ao = Aorta; PA = Pulmonary artery; RA = Right atrium; RV:LV = Right ventricle/left ventricle ratio; SD = Standard deviation.

### Table 2.

<table>
<thead>
<tr>
<th>Variable</th>
<th>CT Mean or Median</th>
<th>SD or Range</th>
<th>Echocardiography Mean or Median</th>
<th>SD or Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV free wall (mm)</td>
<td>4.87 ± 0.27</td>
<td>5.36 ± 0.36</td>
<td>RA length (mm)</td>
<td>20.30 ± 1.12</td>
</tr>
<tr>
<td>RV medium diameter (mm)</td>
<td>21.63 ± 2.32</td>
<td>19.31 ± 1.47</td>
<td>RA diameter (mm)</td>
<td>23.31 ± 1.79</td>
</tr>
<tr>
<td>RV basal diameter (mm)</td>
<td>18.88 ± 2.41</td>
<td>18.92 ± 2.04</td>
<td>RV diameter (mm)</td>
<td>21.63 ± 2.33</td>
</tr>
<tr>
<td>RV length (mm)</td>
<td>37.53 ± 35.95-41.60</td>
<td>37.47 ± 36.67-40.03</td>
<td>LV diameter (mm)</td>
<td>24.25 ± 1.92</td>
</tr>
<tr>
<td>PA diameter (mm)</td>
<td>12.74 ± 1.67</td>
<td>14.56 ± 0.94</td>
<td>RV:LV ratio</td>
<td>0.89 ± 0.10</td>
</tr>
<tr>
<td>Aortic diameter (mm)</td>
<td>14.41 ± 1.61</td>
<td>17.48 ± 0.59</td>
<td>Note: Data are expressed as mean and standard deviation, except for nonparametric data, shown as median or range. Ao = Aorta; CT = Computed tomography; PA = Pulmonary artery; RA = Right atrium; RV:LV = Right ventricle/left ventricle ratio; SD = Standard deviation.</td>
<td></td>
</tr>
<tr>
<td>PA:Ao ratio</td>
<td>0.88 ± 0.07</td>
<td>0.83 ± 0.05</td>
<td>Note: Data are expressed as mean and standard deviation, except for nonparametric data, shown as median or range. Ao = Aorta; CT = Computed tomography; PA = Pulmonary artery; RA = Right atrium; RV:LV = Right ventricle/left ventricle ratio; SD = Standard deviation.</td>
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</tr>
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</table>

### Table 3.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Intraobserver CV%</th>
<th>Interobserver CV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV free wall (mm)</td>
<td>5.13</td>
<td>10.55</td>
</tr>
<tr>
<td>RV medium diameter (mm)</td>
<td>3.80</td>
<td>3.27</td>
</tr>
<tr>
<td>RV basal diameter (mm)</td>
<td>6.39</td>
<td>4.88</td>
</tr>
<tr>
<td>RV length (mm)</td>
<td>3.52</td>
<td>2.59</td>
</tr>
<tr>
<td>PA diameter (mm)</td>
<td>7.31</td>
<td>5.40</td>
</tr>
<tr>
<td>Aortic diameter (mm)</td>
<td>6.25</td>
<td>5.23</td>
</tr>
<tr>
<td>PA:Ao ratio</td>
<td>7.72</td>
<td>7.21</td>
</tr>
<tr>
<td>RA length (mm)</td>
<td>4.35</td>
<td>19.48</td>
</tr>
<tr>
<td>RA diameter (mm)</td>
<td>4.72</td>
<td>7.14</td>
</tr>
<tr>
<td>RV diameter (mm)</td>
<td>3.80</td>
<td>3.13</td>
</tr>
<tr>
<td>LV diameter (mm)</td>
<td>3.88</td>
<td>10.04</td>
</tr>
<tr>
<td>RV:LV ratio</td>
<td>6.31</td>
<td>7.52</td>
</tr>
</tbody>
</table>

Note: Ao = aorta; PA = pulmonary artery; RA = right atrium; RV:LV = right ventricle/left ventricle ratio; SD = standard deviation.
There was no correlation between the tomographic variables of weight and heart rate. However, there was a strong positive correlation between RV free wall, RV basal diameter, and RA diameter with weight on echocardiography. Therefore, it can be concluded that these variables are influenced by the size of the animal. Future studies validating reference values will need to index such parameters, as previously described (Gentile-Solomon & Abbott, 2016). There was a strong negative correlation between RV diameter on echocardiography and heart rate. At higher heart rates, the ventricular filling time is shorter, and thus the chamber diameter will be smaller.

The basal RV diameter was larger in males compared to females. Although no statistical difference was found between the weights of the animals included in the study, the mean weight of males (13.43 ± 2.68 kg) was higher than that of females (12.43 ± 0.40 kg). Therefore, it is possible that this parameter is influenced by weight and not directly by sex. This difference was not clear due to the low number of animals as well as the homogeneity of the sample.

In the present study, repeatability was satisfactory between duplicate measurements of the CT, and for some parameters, the interobserver analysis showed slightly higher CVs, although with acceptable variability. This is important considering that it is a dynamic test susceptible to interference, and there was a relatively long time (minimum interval of 30 days) between evaluations.

There are a number of limitations to this research. The animals were considered healthy based on clinical evaluation and on echocardiographic and electrocardiographic measurements. However, asymptomatic non-cardiovascular comorbidities cannot be excluded, as specific complementary exams were not performed. The small number of animals and the fact that the population was homogeneous, comprising only one breed, make it impossible to extrapolate the results to all breeds of dogs. The tomographic parameters were measured without the aid of the electrocardiogram, which may reduce the likelihood of taking measurements during the correct period of the cardiac cycle. Furthermore, the absence of a gold standard technique (nuclear magnetic resonance imaging) is another limiting factor.

**Conclusion**

Computed tomography-derived measurements of the right side of the heart are simple to perform, have good repeatability, and have satisfactory agreement for most of the parameters evaluated on the echocardiogram. More studies are needed to validate the reference values as well as to evaluate the diagnostic applicability of this technique for different diseases that affect the right heart.

**Ethics Committee Approval:** Ethical committee approval was received from the Ethics Committee of Federal University of Paraná (Approval no: 35; Date: 2019).

**Peer-review:** Externally peer-reviewed.


**Declaration of Interests:** The authors have no conflict of interest to declare.

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